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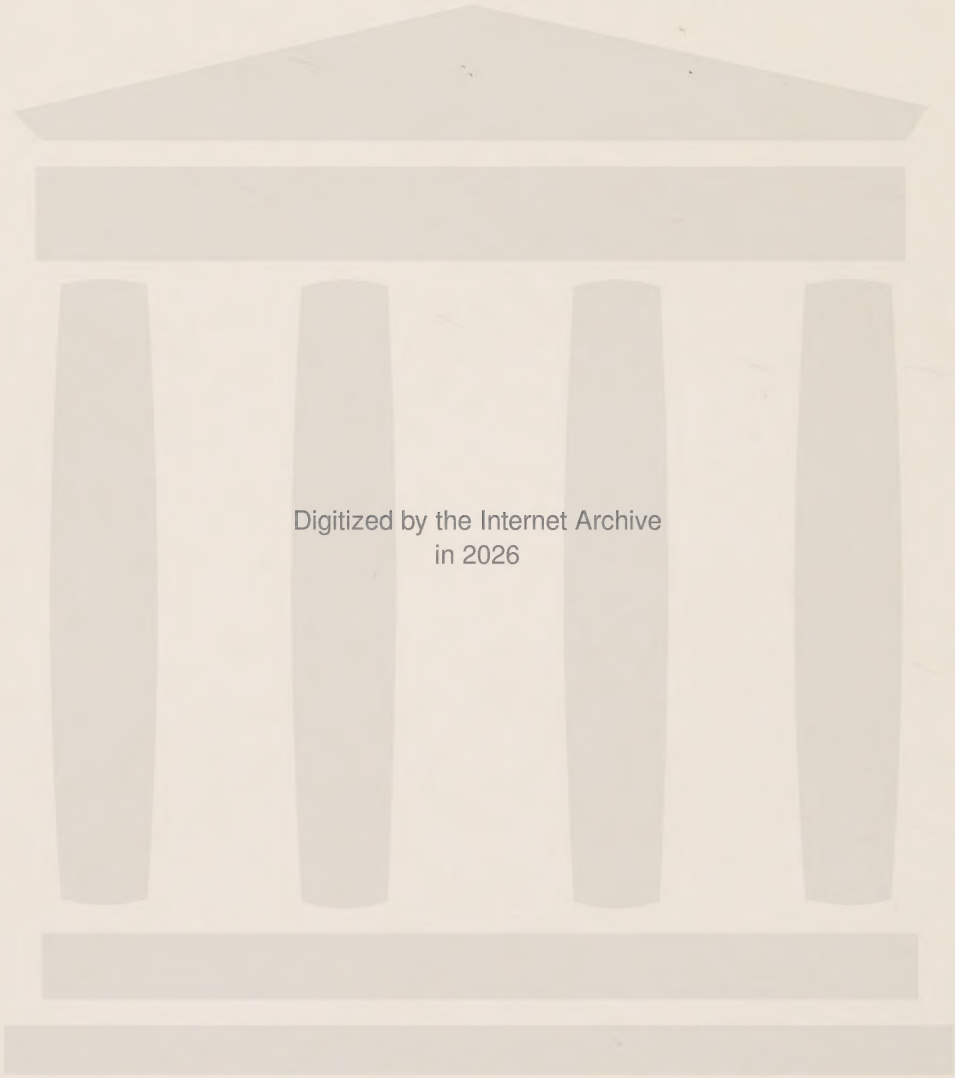

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Republic of South Africa
Department of Environmental Affairs and Tourism
SEA FISHERIES RESEARCH INSTITUTE

RESEARCH HIGHLIGHTS 1994•1995

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An annual publication reporting on research of the past calendar year together with a preview of some to be undertaken

Cape Town 1995

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MISSION OF THE SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable use and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, those involved in fishing, interest groups and the local and international scientific community. The Institute conducts its activities in an open and co-operative manner, functions within the Department of Environmental Affairs and Tourism and strives for excellence in its endeavours.

INTRODUCTION

The Sea Fisheries Research Institute has completed its third year of functioning within a matrix-type structure, a structure which maximizes interdisciplinary interaction, optimizes the available expertise in the country and at the same time allows a great deal of flexibility. In this respect, various working groups which are key elements in the operational system have really come of age and have made it possible for the Institute to function in a cost-effective manner during an exceptionally difficult period. Upon reflection it seems probable that without the organizational and functional restructuring of the Institute in 1991, we would not have been in a position to manage the changes which have taken place in the resources or the environment (both natural and operational). The dedication and flexibility of staff together with the valuable contributions from scientists in other organizations and industry have been the critical success factors in this respect.

The year under review has been characterized by change. The lack of a clearly articulated comprehensive fisheries policy for South Africa has placed added strain on Sea Fisheries and the Institute. Much of the present uncertainty about the future revolves around the problem of access to fish resources. This and other issues are at present being addressed through a fisheries policy development process which was initiated during the second half of 1994 by the Minister of Environmental Affairs and Tourism. The Institute is contributing to the process by providing expert scientific inputs covering a variety of resource-related topics. The present process should facilitate the development of a fisheries policy which will optimize the benefits from a national asset for all.

In keeping with our stated intention of steadily improving the *Research Highlights*, in this, the fourth issue, we have upgraded the standard both of the illustrations and text. Apart from improving visual impact, we trust that our readers will find the latest version more user-friendly and informative. It must once again be stressed that the contents are still only highlights of Institute activities and are not comprehensive all-inclusive accounts of the research, and readers are referred to our house journal *South African Journal of Marine Science* – now in its thirteenth year – and to other publications listed in the last section.

While it is perhaps inappropriate in an introduction to "highlight the highlights" there are a number of important developments to which attention should be drawn. One such development relates to the definitive ageing of the pilchard *Sardinops sagax* resource, which provides conclusive evidence that the pilchard on the West, South and East coasts constitute a single South African stock, which must be managed as such. There has also been a breakthrough with the ageing of chokka squid *Loligo vulgaris reynaudii*, and attention is drawn to the results of the modelling of this resource.

On the international front, the Institute has continued to play a substantial role both in terms of research and management. In June 1994 the first major survey off Moçambique by South African and Moçambican scientists using the F.R.S. *Algoa* took place (assessing the scad resource), and later in the year our scientists participated in the first joint survey of our own waters on a Norwegian vessel, R.V. *Dr Fridtjof Nansen*. With South Africa's membership of the Southern African Developmental Community (SADC) in 1994 and much increased cooperation with Namibia now a reality, the scene is set for regional research cooperation which has hitherto not been possible. In 1994 four meetings of The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) took place

in Cape Town and these highlighted the important role which South Africa is expected to play in the Southern Ocean in the future. With our involvement in ICES (the International Council for the Exploration of the Sea), now also a reality and expectations for increased international cooperation in fisheries research in both Indian and South Atlantic oceans and in international organizations such as the IOC (the Intergovernmental Oceanographic Commission) and the FAO (the Food and Agricultural Organization of the United Nations), the Institute is at last in a position to play its rightful international role. Already within ICCAT (the International Commission for the Conservation of Atlantic Tunas), South Africa is making essential scientific inputs to ensure the sustainable utilization of straddling stocks, e.g. longfin tuna *Thunnus alalunga*.

There are so many other interesting facts in this issue of *Research Highlights* that I would like to touch on, but I shall just mention a few in point form to whet the readers' appetite. These are: the impact of the black tide on the West Coast rock lobster *Jasus lalandii* resource in 1994; the hypothesis on the interactions between sea urchins, abalone *Haliotis midae* and rock lobster in the South-Western Cape; the experimental work on the Natal rock lobster *Palinurus delagoae*; the potential of mariculture as evidenced by studies on *Gracilaria* in Saldanha Bay and on the carrying-capacity of this and other areas for culturing black mussels; environmental predictors of anchovy *Engraulis capensis* recruitment; the role of climate variability and teleconnections with the Pacific *El Niño* Southern Oscillation (ENSO) as determinants of resource availability and abundance on the South Coast; utility of satellite remote sensing as a predictor of anchovy distribution/catches; the really exciting technological developments by the Research Engineering Division, e.g. the ABACUS system; etc.

In concluding this Introduction, mention must be made of two developments which are likely to impact on the Institute in 1995. The first is that both the Director of the Institute and the Deputy Director (Technical Services and Development) have decided, for personal reasons, to accept the offer of early retirement which has been made to all senior Public Servants with long service. This will result in the loss to the Institute (but fortunately not to South Africa) of 65 man-years of expertise. The second development, and one which is really exciting, is that the Institute will be celebrating during 1995 and 1996 its Centenary. One hundred years ago the government of the Cape of Good Hope appointed Dr J.D.F. Gilchrist as the first marine biologist with the express task of developing Cape fishing grounds. Gilchrist was subsequently and concurrently also a Curator of the South African Museum and Professor of Zoology of the South African College (University of Cape Town). He was a brilliant scientist and adviser, and he laid the foundation for marine and fisheries science in South Africa. Various activities are planned to celebrate or coincide with the centenary, including the issue of a commemorative postage stamp, various scientific conferences, the opening of the Two Oceans Aquarium, *Fish Africa '95* and the Gilchrist Marine Festival. What a marvellous way to start a new era in things marine in our new country!

Pelagic fish

At the start of 1994, a revised management procedure covering both pilchard and anchovy was implemented to accommodate some of industry's operational constraints and to provide a less conservative approach to pilchard exploitation in response to improved biomass. The procedure makes allowance for revision to the *TAC*s for both species on the basis of results from the midyear hydroacoustic surveys.

The results from the May 1994 survey indicated the lowest recruitment biomass of anchovy since the start of the time-series in 1985, and the second lowest in terms of numbers of fish. However, the recruits were of a moderate size, probably because of a short period of favourable environmental conditions between October and November 1993. As expected, the spawning survey in November 1994 revealed an extremely low biomass (476 000 tons), close to the lowest on record (that of 1990). Pilchard survey results were more positive, although recruitment was slightly below average. This was sufficient, however, to lead to an estimated spawner biomass in November of 597 000 tons, the highest since the series began in 1985.

In accordance with the revised management procedure, a reduction in the initial anchovy Total Allowable Catch (*TAC*) from 220 000 to 180 000 tons was recommended at midyear, because the end-of-year predictions of spawning biomass were still below the safe threshold. Juvenile pilchard were too abundant in the anchovy catches for the reduction fishery to operate efficiently, and pragmatic options had to be considered when recommending a revised pilchard by-catch *TAC*.

Research on pilchard otoliths was intensified during 1994. The ages of some pelagic fish larvae and juveniles is determined with the aid of a small image-analysis system. The otolith is prepared and mounted under a compound microscope, which is interfaced to a computer via a high-resolution video camera. A special software package permits analysis of the otolith in a few minutes, recording details concerning the size of the otolith, the number of rings, which usually correspond to age, the distance between the rings, which gives the growth rate, and the intensity of each ring. This innovation has considerably speeded up the task of age analysis.

Most interesting of the pilchard research was the results obtained when otoliths taken from commercial landings in Port Elizabeth and during the Kwazulu/Natal "sardine run" were compared with those from the West Coast. The overlapping distribution of otolith length at age one year in all age-groups indicated no apparent differences in growth between the West Coast, the Eastern Cape or Kwazulu/Natal (Fig. 1).

The results confirmed the findings of a study conducted 25 years ago, which indicated that pilchard caught commercially off the southern and eastern coasts should not be regarded as separate resident populations. This means that separate management of pilchard off the Eastern

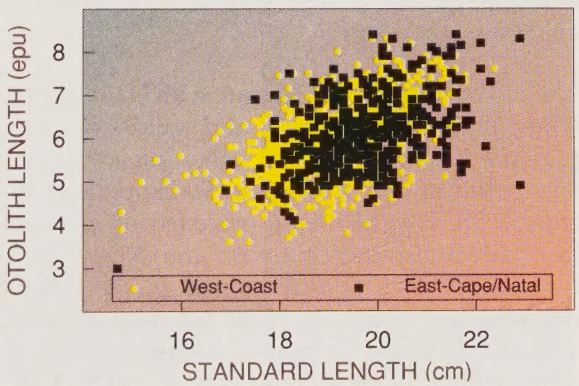


Fig. 1: Scatter plot of otolith sizes at Age 1 from all 2-year-old pilchard caught commercially during the period April – July 1994

Cape and Kwazulu/Natal would have no scientific justification. With the opening of the new field station in Port Elizabeth in mid 1995, more detailed information on regional pilchard landings and their seasonal fluctuations can be expected. This will improve knowledge of pilchard distribution in South African waters and lead to a better understanding of the fluctuations of the resource as a whole.

Demersal fish

Contact with neighbouring countries in the field of demersal research became a major theme in 1994. After some preliminary talks at management level, F.R.S. *Algoa* was used for a biomass survey of the Moçambican shelf in June 1994. The southern two-thirds of the shelf were surveyed at depths of 40 – 500 m in order to estimate abundance of demersal fish, cephalopods and crustaceans, the main targets being several species of scad (*Decapturus* spp.) and deep-water prawns. Problems were experienced with the midwater trawl gear, so the scad could not be assessed effectively, but good results were achieved for the other targets. Although no single species has a high biomass, demersal resources off Moçambique are extremely diverse, and this diversity increases in a northerly direction. More than 500 species were identified, many of which were rare, new to the subregion, or in a few cases, new to science. Some of the interesting species photographed are shown on Figure 2.

The Institute also began liaising with Namibia on hake *Merluccius* research, and guidelines for possible joint surveys and other aspects were laid down at a workshop in Swakopmund in early 1995. This had been preceded by a trawl intercalibration exercise with the Norwegian R.V. *Dr Fridtjof Nansen*, which is currrently deployed off Namibia. Hake biomass surveys will probably be coordinated in future, so that a more realistic biomass index can be obtained for the stocks of both hake species off both countries. There will also be cooperation in other areas, such as stock assessment and ageing methods.

As one of the main foci of a newly launched SANCOR (South African Network for Coastal and Oceanic Research) initiative will be demersal resources, a programme focusing on by-catch species, capacity development and the socio-economic aspects of the demersal fishery has been formulated and is in the process of implementation. A number of students and observers, supervised by researchers from the Institute, Rhodes University, the University of Cape Town and Port Elizabeth Museum, have been recruited to carry out biological studies on the main fish by-catch, and to monitor the rate of discarding and the level of usage of those species.

A major initiative with regard to hake has been the longline experiment, which focuses on the selectivity of longline fishing as opposed to trawling. The results of this work will be an important factor in deciding on the future of a possible longline fishery for hake. More details of this project are given later.

Stock assessment and the provision of *TAC*s for hake remain a major aspect of the research. Some years ago, in consultation with industry, a decision was taken to follow a conservative harvesting strategy, the so-called $f_{0.2}$ strategy, which enhances stock and catch rate recovery, while also permitting small *TAC* increases. Biomass of hake has increased, but there has been some doubt cast on the validity of the catch per unit effort (*cpue*) time-series because of possible improvements in efficiency. A study is therefore underway to investigate and update the so-called power factors applied to the commercial data. Further, the feasibility of using research survey information on the depth-related distributions and size composition of the two hake species, so that the two species can be modelled separately, is also being investigated.

Agulhas sole *Austroglossus pectoralis* research concentrated on gaining a better understanding of factors influencing changes in distribution and catch rates. Agulhas sole are common in certain areas of the Agulhas Bank shallower than 125 m and virtually absent in others.

Fig. 2: *Demersal species collected during the biomass survey of the Moçambican shelf* – *(a)* Lophodiodon calori, *(b)* Ibacus novemdentatus, *(c)* Monocentris japonicus, *(d)* Branchiostegus dociatus, *(e)* Rania rania, *(f)* Hippocampus whitei

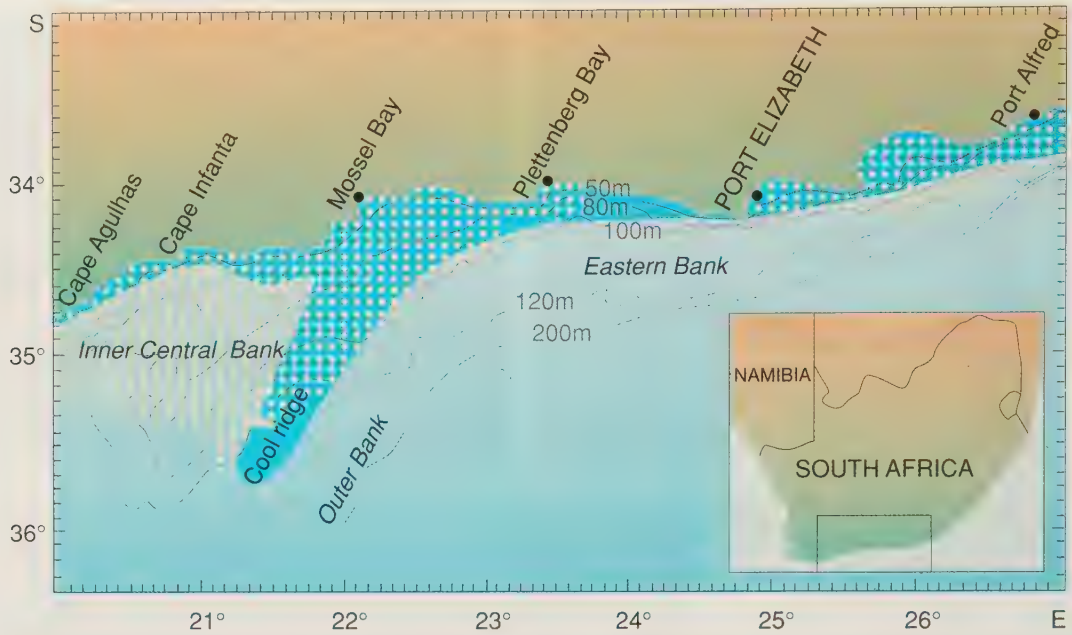


Fig. 3: Spatial distribution of Agulhas sole in relation to depth of the sea bed and the contours of thermocline depth, showing the boundaries and position of the ridge of upwelled water

Current dynamics could, for example, explain the near absence of Agulhas sole in the large area 100 – 120 m deep on the eastern Bank. Sole tend to be absent in localities where the influence of the Agulhas Current is strong, apparently preferring areas with weak current flow.

Other research is comparing the influence of depth of sea bed, bottom temperature and oxygen concentration on the catch rates of sole on the inner central and eastern Agulhas Bank during autumn and spring (Fig. 3). A zone of cold bottom water separating zones of warmer water within the same depth strata is a prominent feature on the Cape south coast. In autumn and spring, the cold water is associated with poor catch rates, whereas catch rates increase in the warmer water. On the inner central Bank (shallower than 75 m), catch rates are high over a larger area in autumn than in spring. Depth is the major factor associated with variability in catch rates, the effects of bottom temperature and oxygen being relatively minor.

The reproductive dynamics of Agulhas sole are also receiving attention. At a body mass of <275 g, most females are mature, but they mature earlier on the eastern Bank than on the inner central Bank, and at a larger size in deeper water. The timing and the extent of the spawning season have important implications for the determination of the birthdate distribution of Agulhas sole. Although there is considerable variation between years, the percentage of

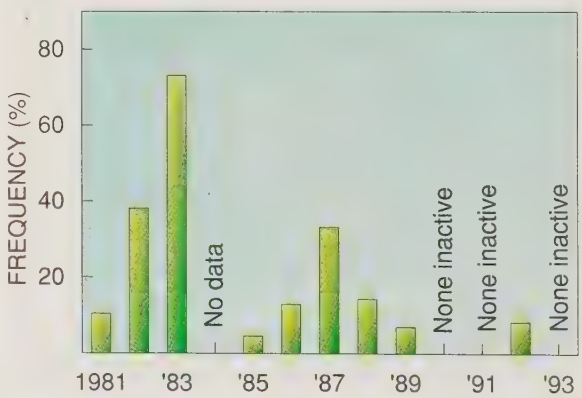


Fig. 4: Average frequency of inactive ovaries of Agulhas sole of 35 – 39 cm during spring (September or October), 1981 – 1993

active ovaries in small sole peaks in April and May, indicating a winter spawning season. Sole >35 cm are reproductively active most of the year, except during years associated with environmental anomalies, such as during the *El Niño*s of 1982/83 and in 1987 (Fig. 4).

Linefish

During 1994 a concerted effort was made to address outstanding questions concerning the state of the southern Atlantic albacore (longfin tuna) resource. Dynamic production model assessments presented to ICCAT during the past four years have presented a consistent picture of slight overexploitation beyond the level of maximum sustainable yield (*MSY*) since about 1985 (Fig. 5). During 1994 all albacore *cpue* data from Japan, the Republic of China and South Africa were reviewed and standardized using general linear models to account for species-targeting effects, gear and vessel effects, and interannual variations. The standardized *cpue* indices were then used to re-run a dynamic age-structured production model stock assessment. The results confirmed that the southern albacore resource is markedly depleted, to about 20% of its pre-exploitation level. Catches have exceeded the estimated *MSY* of 25 000 metric tons since the mid 1980s and current catch levels are not sustainable. South Africa therefore called for a limitation of the species to 10% less than current catches. This recommendation to ICCAT was supported, and if implemented would result in a *TAC* of approximately 4 800 metric tons for South African albacore fishermen.

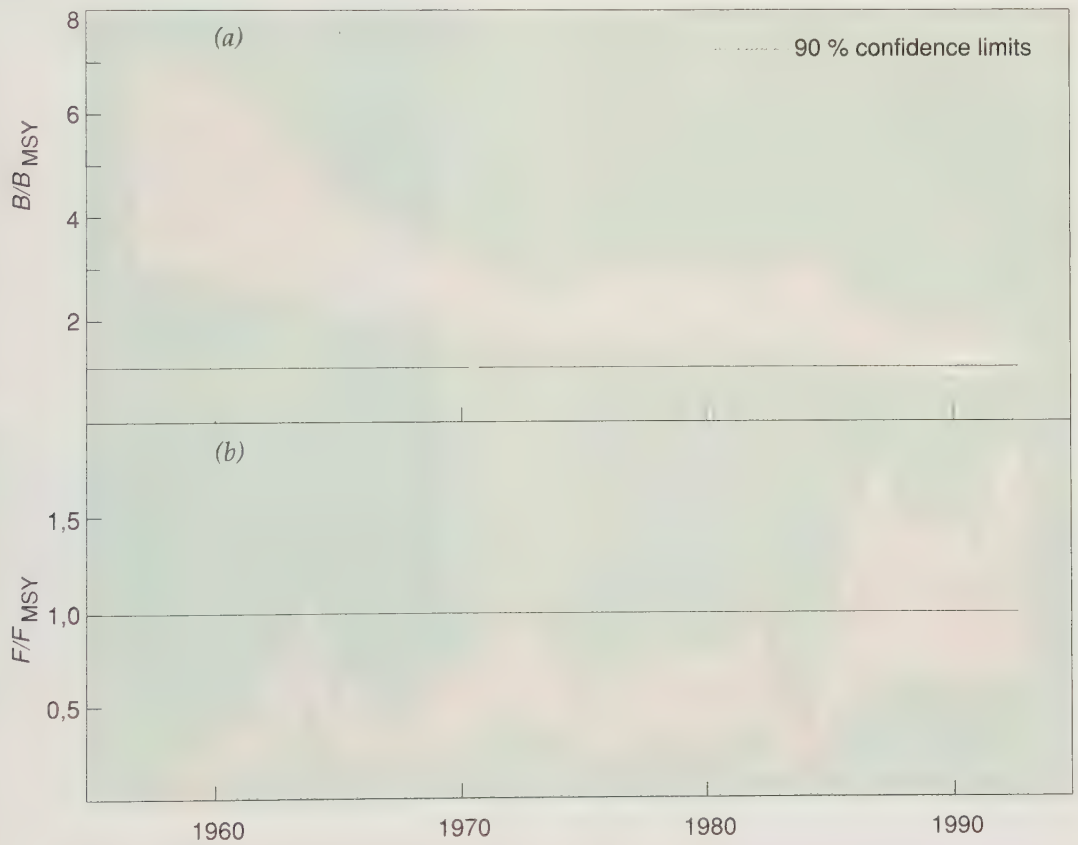


Fig. 5: Production model assessment of trends in the ratio of (a) existing biomass and (b) fishing effort to the biomass and effort at MSY *for the southern Atlantic albacore*

The project on biology and management of kob has confirmed the existence of more than one species in our waters. The southern African kob, until now assumed to be *Argyrosomus hololepidotus*, has been found instead to consist of four different species. The true *A. hololepidotus* only occurs in Madagascar, whereas the South African kob consists of two species, *A. inodorus* (a new species) and *A. japonicus*. *A. inodorus* is a cool-water species confined to the Cape. East of Cape Agulhas it is found in depths of 10 – 100 m, but west of Cape Agulhas it is limited to the surf zone. It has a size at 50% maturity of 350 mm and attains a maximum mass of 34 kg. *A. japonicus*, on the other hand, occurs along the entire east coast from Cape Point to Moçambique, using estuaries and the surf zone as nursery areas. It attains 50% maturity at about 1 000 mm and grows to a maximum mass of 75 kg (Fig. 6). Owing to concern expressed by linefishermen about the capture of undersize *A. inodorus* by inshore trawlers, an observer programme was initiated to examine the impact of trawlers on linefish. Results so far indicate that linefish are only trawled in significant numbers in winter and that total annual trawl catches are much smaller than those reported by the commercial linefishery. Although inshore trawlers do catch juvenile *A. inodorus*, they do not operate in water depths of <50 m, and so do not exploit the main nursery areas.

The linefish section is currently involved in co-ordinating a three-year project to evaluate participation in, and management of, the South African linefishery. There are four regional projects, run by the Oceanographic Research Institute in Kwazulu/Natal, Rhodes University in the Eastern Cape, the University of Cape Town in the Western Cape and the Sea Fisheries Research Institute on the West Coast. The project has been designed to provide a comprehensive "snapshot" of participation in the entire South African linefishery by all sectors, including commercial, recreational, artisanal and subsistence fishermen. It includes a socio-economic evaluation of the various sectors involved in linefishing, and it will provide essential information needed to devise effective management measures for the competing fishery sectors.

Between Cape Point and Port Nolloth, the recreational fishery was monitored by conducting 237 coastal patrols covering 2 563 km of coast (Fig. 7). An average of 0,3 rods was encountered per kilometre, most fishermen targeting galjoen *Dichistius capensis* or white stumpnose *Rhabdosargus globiceps* (Langebaan/Saldanha area). Interviews revealed that most (87%) thought that fishing has declined, citing the main reasons as pollution or the effects of trek nets and trawlers. Most (71%) were against the present bag limits for certain species, but agreed with the need for closed

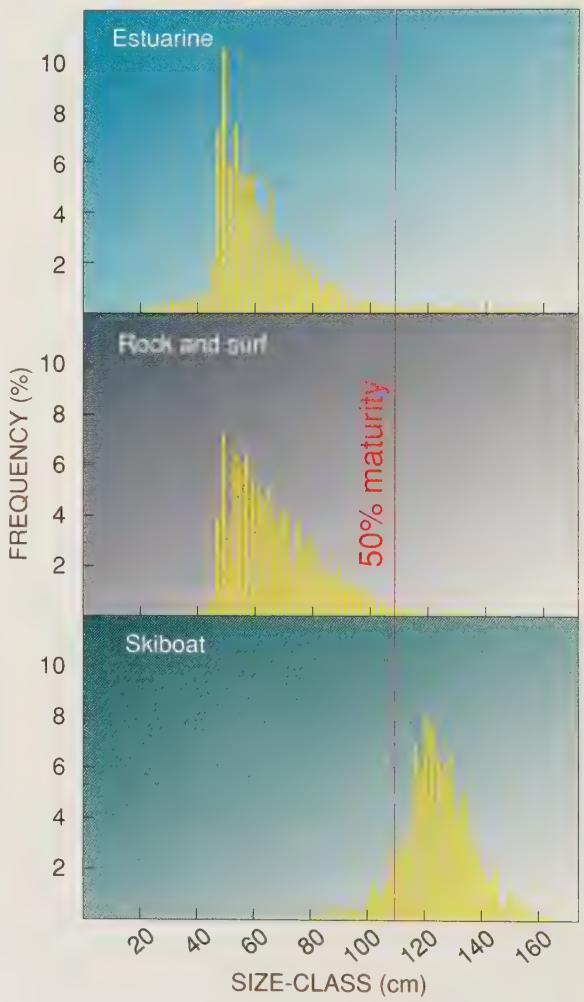


Fig. 6: Length distribution of kob Argyrosomus japonicus *caught by linefishermen along the east coast of South Africa, 1991 – 1993*

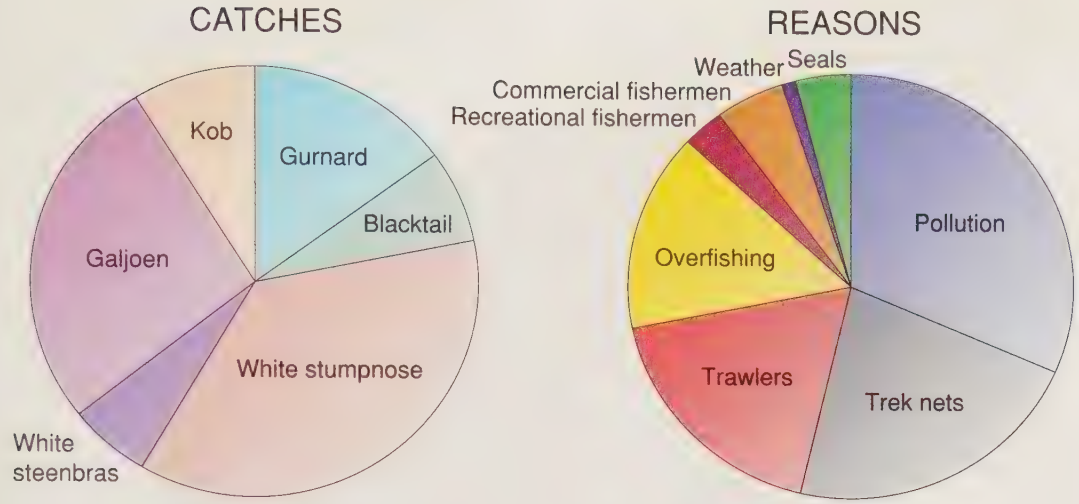


Fig. 7: Results of angler surveys along the Cape west coast during 1994, showing the proportion of fish caught by shore-anglers, and the reasons given for observed declines in fishing success

seasons and marine reserves. Most rock-and-surf anglers (63%) were willing to pay an annual licence fee, suggesting fees of between R5 and R500 per year. The majority of the recreational and commercial boat fishermen interviewed also felt that fishing success has declined; they considered trawling to be the main reason. Most boat-fishermen interviewed disagreed with bag limits as a management measure, but agreed with size restrictions, closed seasons and marine reserves.

Squid

The squid research programme aims to develop suitable research techniques to investigate squid (mainly chokka squid) population dynamics, and to use those techniques to improve management of the resource. Globally, the basic techniques for studying squid ecology, in contrast to those applied to fish, are still in the process of development. This means that squid resources tend to be inadequately managed and controlled.

Some recent scientific achievements have contributed towards better management procedures that may be applicable internationally. For example, a set of decision rules, developed to determine the duration of the closed season, were readily accepted by the industry as a valid management method. Other aspects of an Operational Management Procedure (OMP) are also being developed, including models which incorporate the distribution and magnitude of effort and a time-series of *cpue* in both the jigging and the trawling fishery.

New ideas are being explored in stock assessment, particularly the use of a technique that combines the results of hydroacoustic surveys, bottom trawling and tagging. A cruise in November 1994 showed that a semi-random bottom trawl survey in shallow water between squid concentrations is technically feasible and can provide useful results. At the same time, valuable data on squid migration and concentration stability on the individual and population scales were collected in collaboration with a Canadian research team. A detailed account of this project is given later.

A breakthrough in ageing squid was the field validation of daily increments in squid statoliths. Cooperative research with the National Accelerator Centre on the deposition process in statoliths continued, the aim being to understand the periodicity of daily increments in the statolith. The working hypothesis is that strontium is responsible for good definition of

Fig. 8: Nuclear microprobe scan of a chokka squid statolith, sectioned in the frontal plane and showing the strontium (Sr) content

increments. If this fact is confirmed, areas with high strontium content can be identified (Fig. 8) and increments easily separated from other structures, a major stumbling block of existing techniques. The ultimate objective is to bypass the very difficult and costly validation procedure for any species of squid.

A technique allowing refined assessment of maturity was developed, resulting in a more balanced picture of squid biology on the spawning grounds as well as being useful in studies on gonad histology. A model of squid survival was completed and has been used for the analysis of stability in squid concentrations, a factor which

will be taken into consideration in stock assessment. Bias in data collection by means of jigging was assessed, revealing that proportionally fewer small squid, especially females, are caught on jigs than are present in the concentration.

A project on the food and feeding of paralarvae has provided proof that antibodies obtained from their planktonic prey are sufficiently specific to use for identification purposes. Positive results will also allow conclusions to be drawn about paralarval survival under various environmental conditions. These results will be compared with the theoretical mortality rates from the survival model.

Abalone

In response to concerns that the generally positive trends shown by such fishery indices as *cpue* might not accurately reflect the status of the resource, a fishery-independent abalone survey was initiated. A comprehensive survey design was based on analysis of historic abundance data, kelp maps and past diving survey experience. These intensive diving surveys, which entail swimming numerous 30 m transects in each of the fishing zones, as well as closed areas, are already underway and will be repeated annually. It is hoped that they will provide an index of abalone abundance which, once trends are established, can be used towards the annual assessment of the state of the resource.

Monitoring of recruitment cycles was curtailed during 1994 owing to the imminent implementation of the programme detailed above. The two surveys carried out showed no new settlement at Robben Island, but recruitment at Betty's Bay, although only after considerable searching. The latter observation was attributed to the unexpected absence of usually abundant sea urchins, which provide shelter for the recruits. A similar decline in the number of sea urchins (and consequently in abalone recruits) was noted at Mudge Point in March 1995, and at both sites this phenomenon appeared to coincide with an increase in abundance of rock lobsters in the area. However, more data are needed to substantiate the theory that predation by rock lobsters may be the cause of the decline in sea-urchin abundance. Normal sea-urchin density and abalone-recruit abundance were recorded at Danger Point in 1994 and early 1995. It is hoped to renew monitoring of the important abalone recruitment cycles, using a modified survey design, in a year or two.

Landings by recreational abalone divers were measured at a number of sites during December and January to provide size composition data for that sector of the fishery. Sales of recreational abalone-diver permits continued to escalate, as they have been doing for the past six years, to total 33 088 permits for the 1993/94 season (Fig. 9). Monitoring of these licensed recreational abalone divers through telephonic interviews continued into its third year. The interviews yielded an estimate that almost 550 tons of abalone, 89% of the commercial quota of 615 tons, were taken by such divers in 1993/94 (Fig. 9). The average number of abalone taken per permit-holder also increased from 20 to 24 per person. Management measures for limiting the expanding recreational fishery have yet to be implemented.

Poaching of abalone appears to have increased, with much media coverage during the latter half

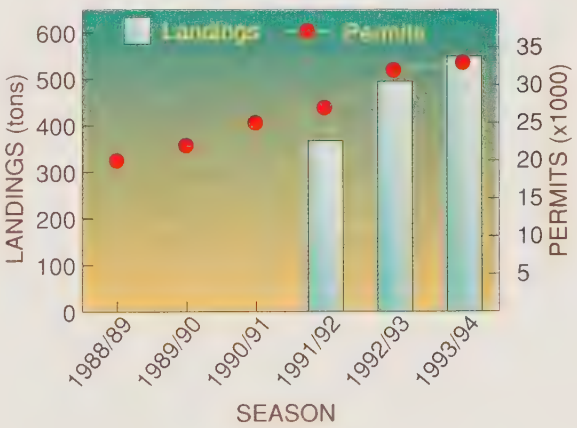


Fig. 9: Sales of abalone permits to recreational divers since 1988 and recreational abalone landings as estimated from telephone surveys conducted during the past three seasons

of 1994. A morphometric study was carried out at three stations in order to obtain conversion factors for estimating original shell dimensions from flesh mass. As poachers usually shuck the abalone from their shells before transportation, this allows estimates to be made of the proportion of abalone below the legal minimum size in confiscated hauls. Some of those hauls consisted of as much as 85% below the minimum legal size, so size limits clearly mean little to poachers. This conclusion was supported by the contents of a bag of whole abalone confiscated from poachers at Mudge Point in March 1995 (Fig. 10).

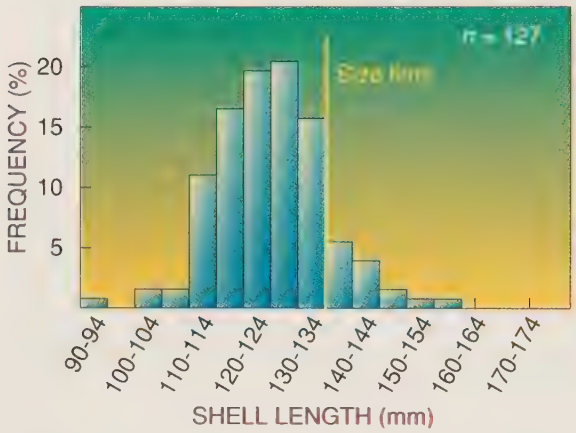


Fig. 10: Size distribution of a bag of abalone confiscated from poachers at Mudge Point in March 1995

Given the large volume of abalone being illegally harvested, this has major negative implications for the sustainability of present harvest levels, as abalone are being removed from the population before fulfilling their reproductive potential. If control mechanisms are not implemented more effectively, the resource is unlikely to continue supporting existing catch rates in future.

Rock lobster

Growth and production rates of West Coast rock lobster remained low on most fishing grounds. Despite the decrease in minimum size from 80 to 75 mm, the 1993/94 *cpue* of commercial fishermen in the northern areas still decreased slightly. This, together with the slower growth rates and the "black tide" event which resulted in a massive lobster mortality in St Helena Bay (Fig. 11), led to a reduction in the *TAC* from 2 200 tons in 1993/94 to 2 000 tons in 1994/95. A new trap design, incorporating escape-gap grids to reduce the numbers of undersized lobsters reaching the surface, was introduced at the start of the 1994/95 season, and for their first season, 10% of all industry traps were modified to comply with the new design.

A diving survey of North Blinder and Britannia Blinder, two important fishing areas in the St Helena Bay area, immediately after the black tide event revealed not only a complete absence of lobsters, but also a sea bed, usually dominated by sponges, devoid of all benthic life. Subsequent diving surveys there have indicated a recolonization by juvenile black mussels and a few rock lobsters. The continued recovery of lobster abundance in these two areas and the shift from a sponge-dominated benthic community to one dominated by mussels will be carefully monitored in future.

Recent research has also revealed that, under field conditions, both sexes of rock lobster are capable of negative growth, or shrinkage, at moulting. Re-examination of past growth-rate data, which ignored negative growth, showed that the percentage of tag returns indicating shrinkage was highest when mean growth rates were lowest, and vice versa. Growth records have been modified to include negative growth in the light of these findings.

A telephone survey, designed to estimate the quantity of lobsters harvested by recreational permit-holders, indicated that more than 57 000 permits were issued over the 1993/94 season, a decrease of 3% from the previous season. Each permit-holder also caught an average of 20 lobsters during the 1993/94 season, three fewer than the previous season. The total recreational catch in 1993/94 was estimated at 391 tons, some 17% less than that estimated for the 1992/93 season.

Modelling exercises suggested that the 1993/94 *TAC* of 477 tons tail mass (including the 25 ton

Fig. 11: The "black tide" at St Helena Bay during March 1994 killed thousands of rock lobster

Ciskei allocation and two tons for research) for South Coast rock lobster *Palinurus gilchristi* may have been above the sustainable level. A precautionary *TAC* 10% lower was therefore introduced at the start of the 1994/95 season and further modelling work undertaken. The results of this modelling resulted in the final TAC for the 1994/95 season being reduced to 452 tons, with a clear indication of a further 25 ton cut being likely for the next season. The gathering of accurate size composition data for South Coast rock lobster by an on-board researcher was initiated at the start of the 1994/95 fishing season.

An experimental deep-water longline trap fishery for Natal rock lobster was launched in 1994. The experiment, using standard South Coast vessels, lines and traps, was aimed at determining the distribution and abundance of *P. delagoae* in the area between the Moçambican border and Transkei. Each vessel was accompanied by a research monitor and the longlines were deployed at predetermined stations. An overall lobster abundance index of 446,8 $g \cdot trap^{-1}$ was found during the survey, *P. delagoae* constituting 67,6% and the slipper lobster *Scyllarides elisabethae* 32,4%. The effects of depth, width of continental slope and latitude on *P. delagoae* size composition and *cpue* were also assessed. Further research is required before the viability of a commercial longline trap fishery in this area can be determined.

Seaweed

Studies at Saldanha Bay have improved understanding of the biology of *Gracilaria verrucosa*, which continues to wash ashore and is collected for export as an agar source. Research data have shown that natural, bottom-dwelling populations usually maintain a high biomass throughout summer because of the presence of nutrient-rich water below the thermocline. By contrast, plants cultivated near the surface may stop growing and become bleached in midsummer, owing to the prolonged presence of a warm,

nutrient-poor surface layer. Nevertheless, growth rates of surface plants are high during the rest of the year, and more than three years of experimental data show that cultivation of *Gracilaria* at Saldanha Bay is feasible, and could be expected to produce about 60 – 70 tons (dry mass) per hectare per year. There is considerable commercial interest in mariculture of *Gracilaria* to supplement the variable natural supply and to improve control over the quality of the raw material.

A demand for fresh kelp *Ecklonia maxima* as feed for cultured abalone led to an experimental harvesting programme being initiated in 1991 at Danger Point, and several results are now apparent. Harvesting of all kelp plants taller than 0,5 m has had no effect on the biomass or diversity of other benthic understorey fauna and flora. Kelp recruitment through settlement of sporelings was poor for two years and almost entirely restricted to the holdfasts of bigger plants, where sporelings are less accessible to grazers, particularly sea urchins (Fig. 12). The recovery of harvested lanes of kelp was therefore slow. Good sporeling recruitment away from holdfasts was observed only in the third year after harvesting, and the beds are now recovering. This large data set is being analysed in order to make recommendations for management.

Fig. 12: A diver samples benthic organisms in kelp beds at Danger Point as part of a study on the effects of kelp harvesting

In the past, several species of carrageenan-producing red seaweeds were collected in the Western Cape and exported for extraction of this valuable colloid. Although the resource has not been exploited for nearly two decades, increasing demand for carrageenan suggests that these species may be collected and probably also cultivated in future. Studies of the biology of the most important species, particularly *Gigartina polycarpa* and *Sarcothalia stiriata* are therefore in progress. Results obtained so far show that growth rates of these young plants exceed 39 mm·month^{-1}. Turnover rates in a natural population are higher than expected, up to 75% of tagged plants being lost after even moderate swells. Plants may lose a large part of their fronds during storms, but rapid growth or replacement maintains the population. Such features are likely to make both species suitable for repeated harvesting, whether of natural or cultivated stocks.

As the red seaweed *Porphyra* is potentially harvestable as human food and for feeding to cultivated abalone, it is being studied by a University of Cape Town researcher under contract to the Institute. The biomass of *Porphyra* is greatest on the western side of the Cape Peninsula, particularly at Kommetjie and Soetwater. What was previously called *P. capensis* has now been found to be a complex of at least three species, and electrophoretic and culture methods are being used to distinguish them.

HIGHLIGHTS OF SUPPORTING RESEARCH

Climate change and Agulhas Bank fisheries

In 1991 a research programme, the South Coast Climate-Oceanography-Fisheries Interaction Study, was initiated to investigate the reasons for the large fluctuations observed in the chokka squid fishery. The programme consists of four phases. Phase I identifies environmental parameters and formulates hypotheses about how these parameters impact chokka squid catches. Phase II investigates physical and chemical processes to increase understanding of seasonal and annual variability. Phase III develops a conceptual model in order to focus future research and test the hypotheses formulated in Phase I. Finally, Phase IV transforms the conceptual model into a practical predictive capability.

Phase I has been completed and has revealed that exceptionally good catches of chokka squid correspond to low temperatures of the coastal water, whereas poor catches occur when bottom turbidity is high on the benthic spawning grounds. It is thought that high benthic turbidity hinders the visual communication process necessary to ensure successful mating between male and female. The project (in St Francis Bay) demanded innovative application of instrumentation. Therefore, a self-contained wave-height recorder with a deployment capability of two months was developed. Levels of particulate matter in the water column are monitored using optical back-scatter in a specialist instrument designed and built in-house. Low-light-level video technology has been applied in conjunction with differential GPS to map the sea floor and biota. Patches of squid habitation are emerging. The St Francis Bay work has been a learning ground for shallow, high-energy water deployment of instruments.

Phase II of the programme, which is currently in progress, has shown that coastal water temperatures decrease along the South Coast in response to easterly winds during summer. These winds are moderated by the activity mode (positioning) of the South Atlantic and South Indian Ocean Anticyclones, which varies interannually, causing certain summers to be windier than others. The anticyclones are also strongly influenced by large *El Niño*/Southern Oscillation (ENSO) Events, the frequency of easterly winds having been shown to be greatly reduced during *El Niño* events and greatly increased during *La Niña* events. Preliminary evidence also suggests that bottom turbidity either increases or is maintained at high levels during *El Niño* summers as a result of the continued dominance of westerly winds and sustained ground swell.

Agulhas sole have recently been included in the programme because it is now known that the winter swell which continues into *El Niño* summers markedly influences the benthic environment of the inner central Agulhas Bank, the main area for sole spawning and fishing. The effects of the maintained swell are a suppression of the summer thermocline and unusually warm bottom temperatures throughout summer. It is uncertain how this alters sole behaviour, but it is noteworthy that *El Niño* summers correspond to poor catch rates and increased ovary inactivity.

Environmental factors affecting mussel farming in Saldanha Bay

Research aimed at establishing the carrying capacity of Saldanha Bay for mussel (*Mytilus galloprovincialis* and *Choromytilus meriodionalis*) farming led to considerable advances in understanding the physical, chemical and biological processes which impact on both mussel food (phytoplankton) and water quality (oxygen).

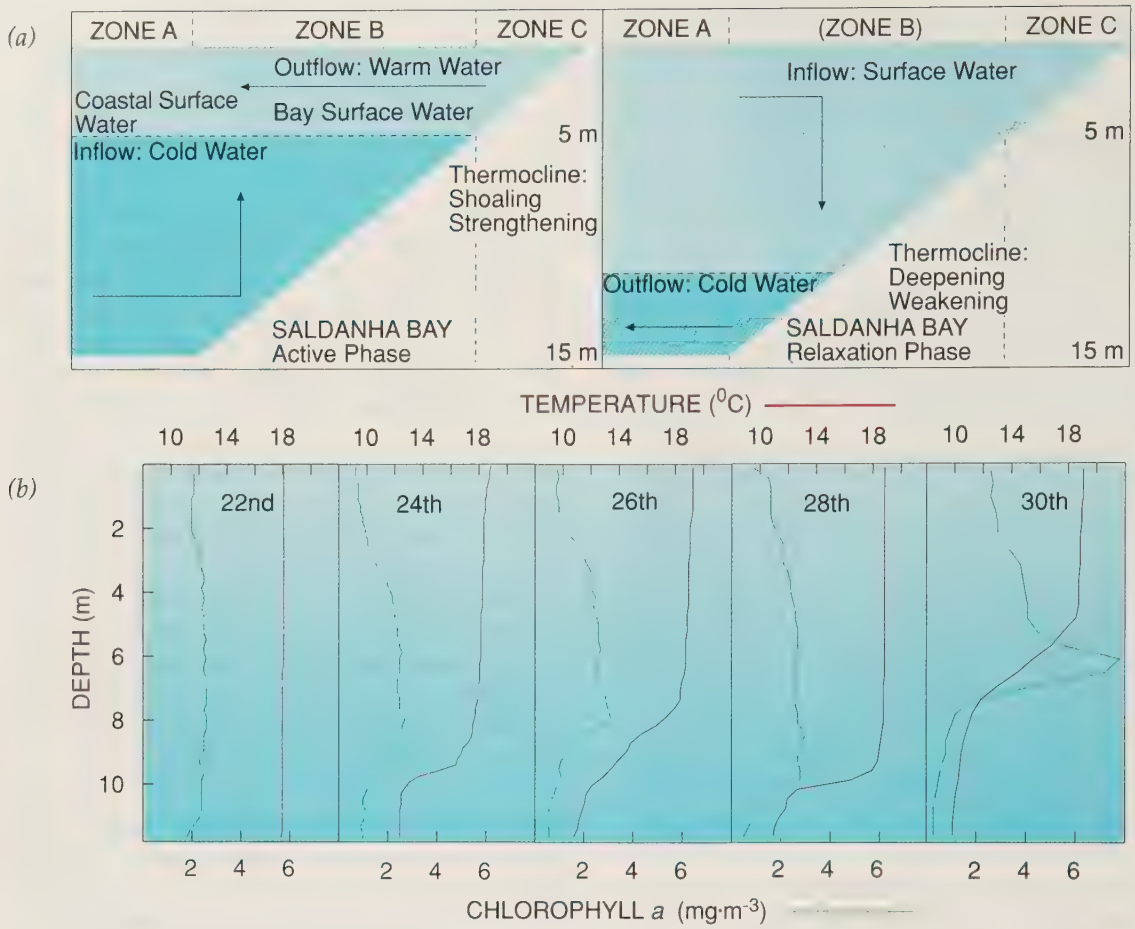


Fig. 13: (a) Schematic diagram depicting the physical processes and (b) a time-series of temperature and chlorophyll profiles during "active" and "relaxed" phases of the synoptic cycle in Saldanha Bay

Central to this understanding was the discovery of the oscillating behaviour of the Bay's water column between two phases (Fig. 13a). In the "active phase" cold, nutrient-rich bottom water is pushed into the Bay from the shelf, resulting in the outflow of surface water and a shallowing of the thermocline. During the "relaxation phase" the external driving mechanism is "turned off", the cold bottom water flows out of the Bay and it fills with well-oxygenated, nutrient-poor warm water.

The impact of this oscillation on the mussels' phytoplankton food source is evident from a time-series of temperature and chlorophyll profiles (Fig. 13b). During the relaxation phase the entire water column is characterized by warm water and low concentrations of chlorophyll, but during the active phase a subsurface phytoplankton maximum develops in association with the thermocline.

In terms of the impact on water quality, the active phase bottom-water inflow is a mechanism by which low-oxygen water from the shelf is imported into the Bay, as after the southward flow of anoxic water from the St Helena Bay "black tide" in March 1994. During the relaxation phase, however, the inflow of well-oxygenated surface water ventilates the Bay in a flushing effect, which is likely to mitigate against the long-term impacts of pollution or

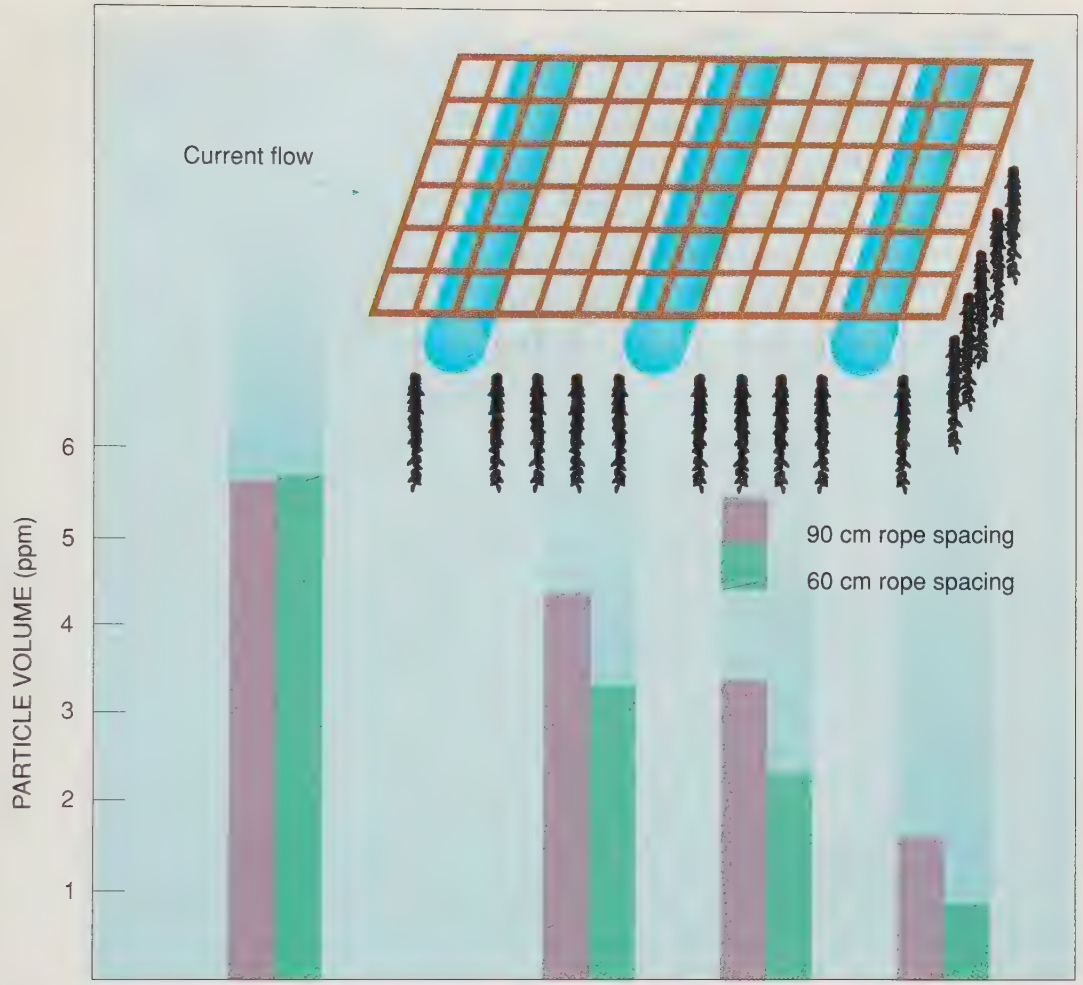


Fig. 14: Particle removal from the water as it passes through mussel rafts with rope spacings of 60 and 90 cm

natural eutrophication. In addition, the relaxation phase serves as a mechanism by which surface red-tide blooms, a serious threat to the mussel-farming industry, can be rapidly imported into the Bay.

In a collaborative project with the Department of Ichthyology and Fisheries Science at Rhodes University, the relationships between food availability, stocking density and overall mussel production have been investigated. It has been established that a considerable fraction of the phytoplankton is removed from the water as it passes through a mussel raft, and that this fraction is influenced dramatically by the spacing of the mussel ropes on the raft (Fig. 14). Associated with an increase in the distance between mussel ropes and the greater food availability is a statistically significant increase in the growth rate of mussels, thereby providing important information on future raft design.

Mussel-watch programme

One of the first consequences of releasing contaminants into the sea is the accumulation by organisms of these contaminants from their food or the surrounding waters and sediments. Monitoring the concentration of compounds such as heavy metals in the tissues of selected

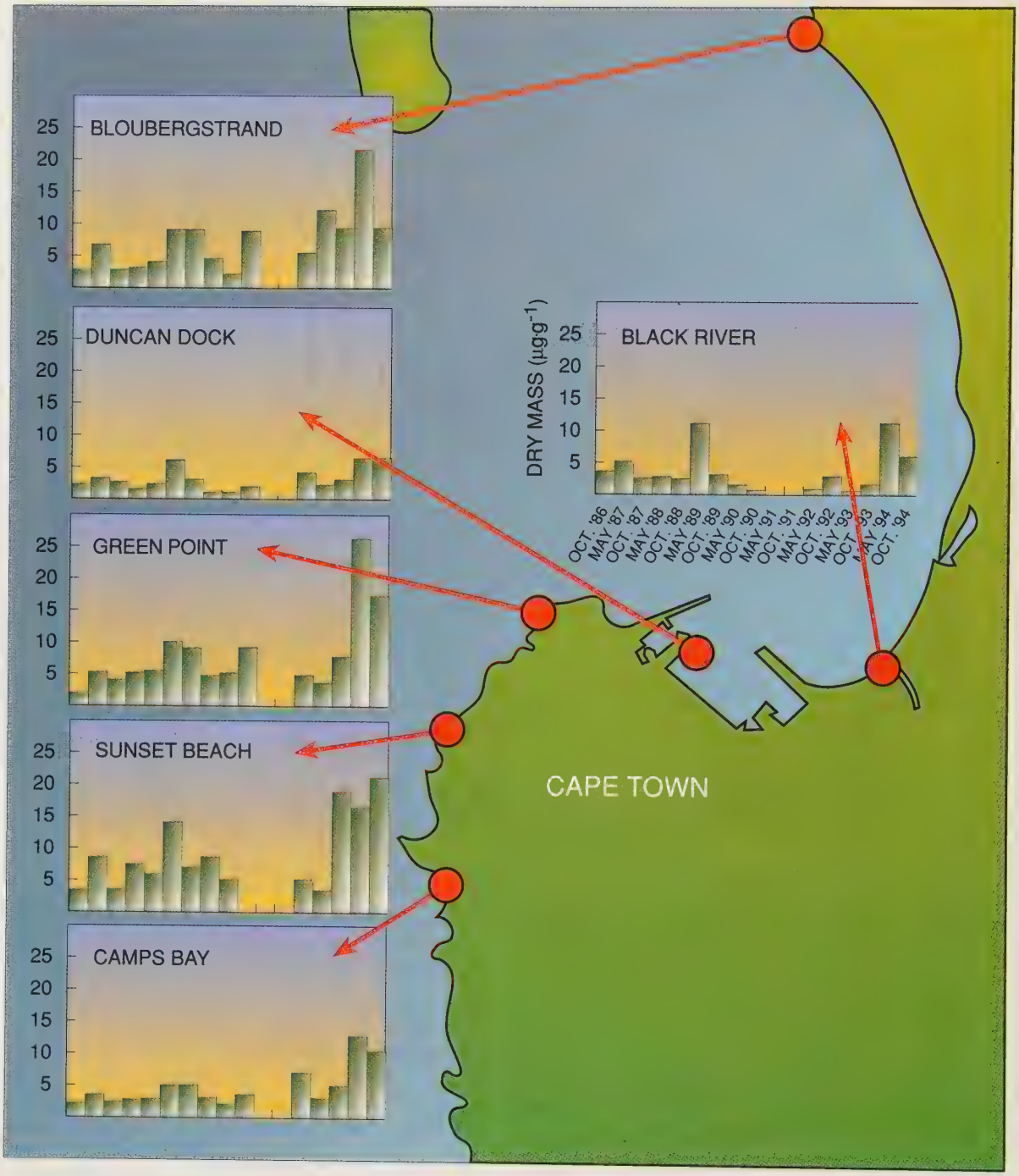


Fig. 15: Time-series of cadmium levels in mussels collected from six sites since 1986

species is therefore a means of quantifying the degree of contamination of the environment. As filter-feeders bioaccumulate contaminants rapidly, a global mussel-watch programme was initiated in North America, and progressed to Europe and the Asia-Pacific zone. At present the Cape Peninsula mussel-watch programme is the only one in Africa.

The local programme assesses the extent of pollution in False Bay, Table Bay and Hout Bay through the measurement of heavy metal concentrations in the mussels *Perna perna* and *Mytilus galloprovincialis*, collected from 40 sites. The heavy metal concentrations are measured in a recently commissioned positive-pressure particle-filtered laboratory, fitted with laminar flow cabinets. The detection limits for some of the metals are in the range of parts per trillion. Detection is done by graphite furnace atomic absorption. The laboratory is the only one in South Africa capable of analysing heavy metals in the full suite of biotic, sedimentary, water and surface film samples. The metals used as indicators are lead, cadmium, copper, mercury, zinc, iron and manganese. Sampling has been carried out twice per year since 1986, excluding a break of 12 months after five years. A further two years of data are required for detailed statistical analysis, but some trends are already obvious.

In Table Bay, the most polluted of the three bays assessed, contaminated sites relative to control sites have on average five, three and two times higher levels for lead, mercury and copper respectively. At the most contaminated sites, close to outfalls, rivers, stormwater drains and the harbour, these levels are considerably higher. In general, the time-series indicates that copper levels have remained constant, whereas cadmium levels have increased (Fig. 15) and lead levels decreased.

Levels of lead contamination in mussels in Table Bay are an interesting case study of the environmental effect of human activity. Petrol in South Africa contains lead tetra-acetate as an anti-knock additive. As a result, lead is deposited on

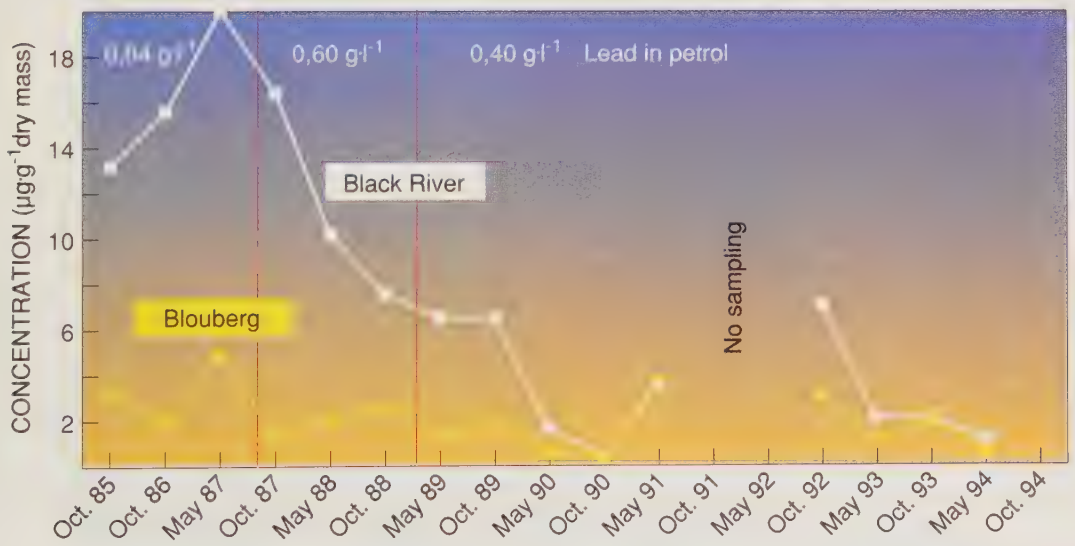


Fig. 16: Time-series of lead levels in mussels collected at the mouth of the Black River, a contaminated site, and at Blouberg, a control site, since 1985

roads through exhaust fumes and spillage, and during rain events these deposits are washed through stormwater drains into the littoral and sublittoral zones. Lead also enters the atmosphere, and it is returned to the sea surface through rainfall and particulate fallout. The mussels are therefore exposed to lead through both pathways.

Since the inception of the mussel watch, lead in petrol has been reduced in two steps from 0,84 to 0,60 to 0,40 $g \cdot \ell^{-1}$ (September 1987 and January 1989). At the contaminated sites there has, to date, been a slight to ten-fold reduction in lead levels in mussels (Fig. 16). Although the environment displays a lag response, and other factors also play a role in lead accumulation in animal tissues, the simultaneous decrease of levels of lead in petrol and in the mussels is unequivocal. South Africa is to phase in totally lead-free petrol from 1996.

As a result of the successful operation of the Cape Peninsula programme, a proposal to broaden the mussel-watch programme to the rest of the South African coast, and possibly even to other countries on the subcontinent, is under consideration.

Environmental predictors of anchovy recruitment

The reduction fishery for anchovy is one of South Africa's most variable on a year-to-year basis, but it is also one of the largest in terms of tonnage landed, and it supports a vast infrastructure of vessels, factories and fishermen. As the bulk of the catch is made up of fish younger than one year, it would facilitate management if recruitment, which appears markedly influenced by environmental factors, could be predicted.

Two of the most promising relationships are with fish oil yields (measured as the oil-to-meal ratio obtained from pelagic reduction factories) and an inverse relationship with south-east winds recorded at Cape Point lighthouse. Within the period 1985 – 1994, high oil yields relate to good recruitment in terms of biomass (Fig. 17a), whereas strong south-east winds relate to poor anchovy recruitment in terms of numbers (Fig. 17b). The rationale for these relationships is that good oil yields are indicative of good food availability to the growing anchovy, whereas strong south-east winds yield poor (cool and turbulent) conditions for spawning and a greater risk of fish eggs and larvae being transported offshore into the deep ocean. In 1986 an intrusion of Agulhas water is believed to have upset both relationships, but they are still statistically significant over the entire time-period.

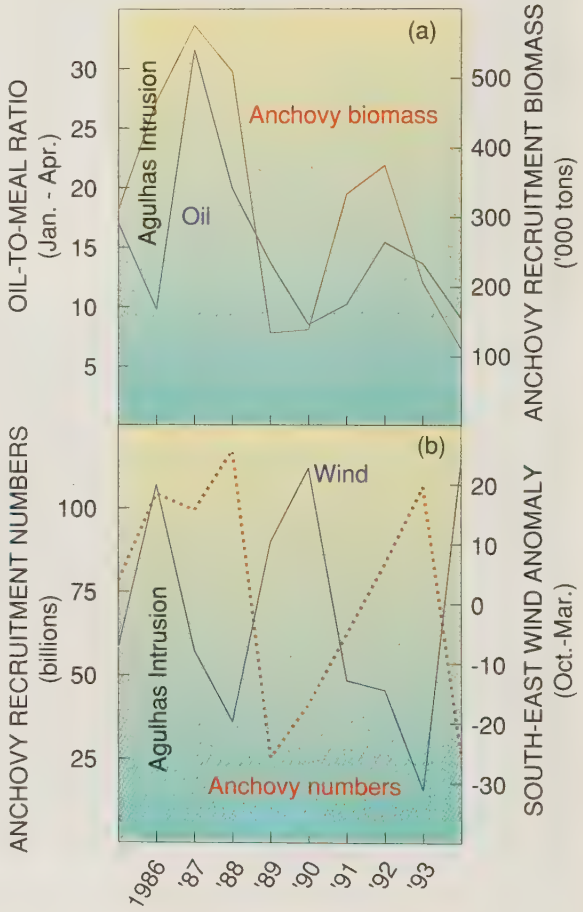


Fig. 17: Anchovy recruitment relative to (a) fish oil yield and (b) south-east wind anomalies, 1985 – 1994

The pelagic pre-recruit survey programme

The Institute initiated a pelagic pre-recruit survey programme during 1990. Its aim is to provide an earlier indication of anchovy recruit strength than was the case in previous years, when it was necessary to wait for the results of the May/June recruit cruises. Since 1990, four pre-recruit surveys have been conducted during March of each year except 1993.

Anchovy use the West Coast as a nursery ground. Therefore, for a short period, the pre-recruits are concentrated in a relatively well-defined area that can be surveyed comprehensively. Sampling is conducted along a grid of randomly spaced transects between the Orange River and Cape Columbine, with seven stations spaced 10 miles apart along each transect. The main sampling gear is the Methot trawl, a rigid-frame trawl with a mouth opening of 5 m^2, which can be controlled to fish at defined depths at a speed of 3 knots. Sampling is carried out only at night to reduce gear-avoidance by the young fish.

The spatial distributions of anchovy pre-recruits for 1992 (a strong year-class), 1994 (a weak year-class) and 1995 (yet to be assessed) are shown in Figure 18. Apart from some gaps in the 1994 map, it is apparent that anchovy are found over the entire area between Cape Columbine and the Orange River, the density increasing near Lambert's Bay and St Helena Bay. In 1992, high densities of anchovy were also found offshore of Hondeklip Bay. It is hoped that an index, such as the number of pre-recruits per 1 000 m^3 of water filtered, can be used in future as a year-to-year comparison of pre-recruit strength.

Methot trawls sample the size range between 15 and 35 mm most effectively, most fish coming

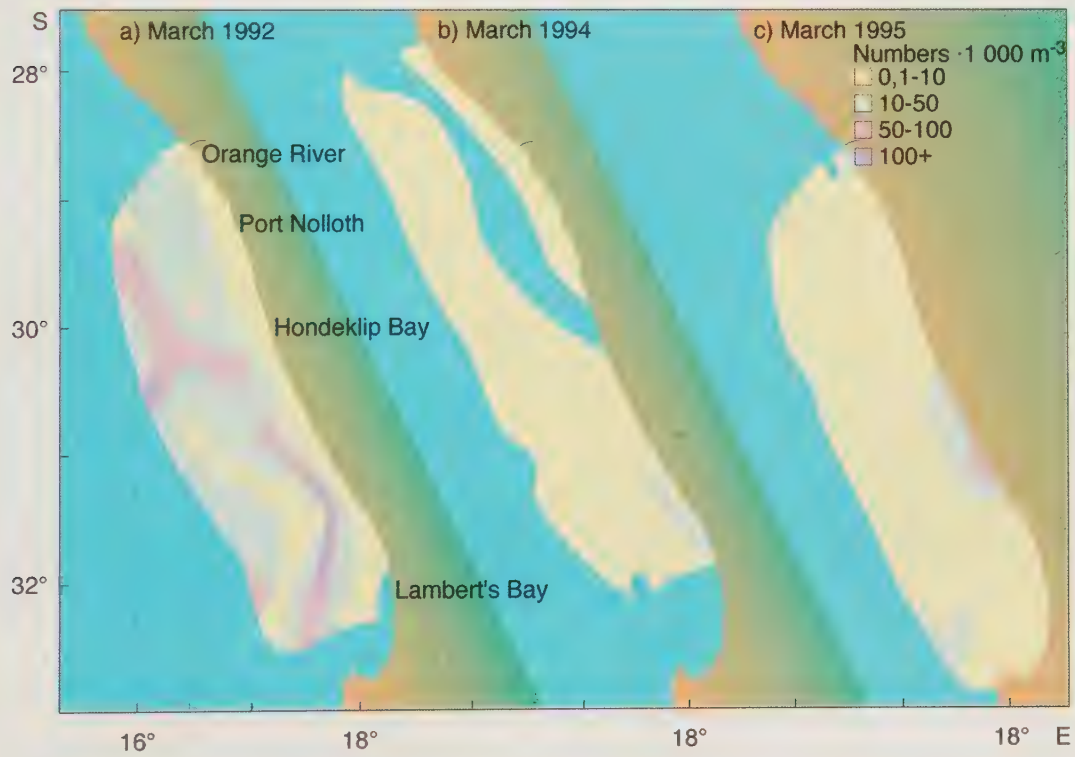


Fig. 18: Spatial distribution of anchovy pre-recruits as measured in March of (a) 1992, (b) 1994, (c) 1995

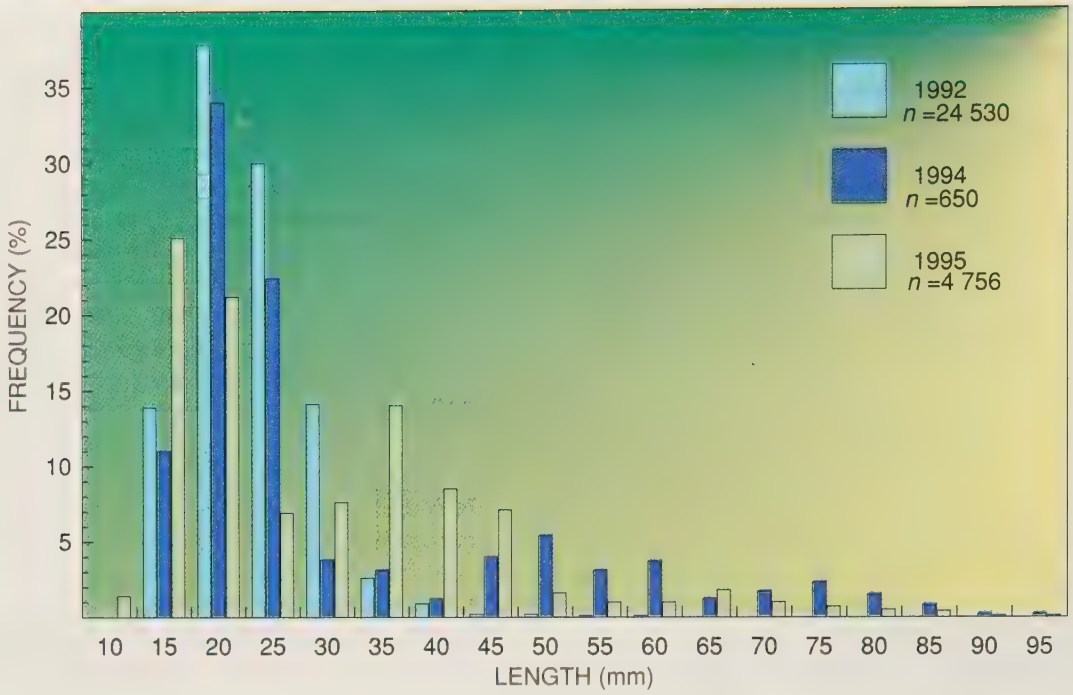


Fig. 19: Size distribution of anchovy pre-recruits estimated from Methot trawl sampling during the pre-recruit surveys of 1992, 1994 and 1995

from the 20 – 25 mm and 25 – 30 mm size groups (Fig. 19). The numbers caught in 1994 were so low that they may be disregarded, but the number of large fish (>35 mm) caught in 1995 was higher than in 1992. This indicated good spawning/survival early in the 1994/95 spawning season, the size of the fish suggestive of spawning in September or October 1994. The simultaneous acoustic and pelagic trawl survey, which is an integral part of the pre-recruit cruise, confirmed a relatively high biomass of juvenile anchovy in the survey area. In fact, the 1995 survey was the first pre-recruit survey to provide a plausible early acoustic estimate of anchovy recruit biomass.

Research to increase understanding of the migration patterns of anchovy larvae and juveniles northwards and shorewards along the West Coast is also being conducted. Acoustic Doppler Current Profiler (ADCP) data on sea currents augment size and positional data for the pre-recruits in order to quantify the movements of the young fish.

The anchovy pre-recruit programme has in the past few years provided the first indication of the relative success of each spawning season, so supplying useful information on the probable timing of the main input to the recruit fishery.

Condition of spawning anchovy on the western Agulhas Bank

Anchovy accumulate to spawn on the Agulhas Bank between September and February each year. During that period the bulk of the spawning population, sometimes as much as a million tons of fish, is concentrated on the western Agulhas Bank between Cape Point and Cape Agulhas, in an area about 180 km long and 90 – 110 km wide. Spawning is serial, batches of eggs being laid at intervals of 7–11 days using energy derived

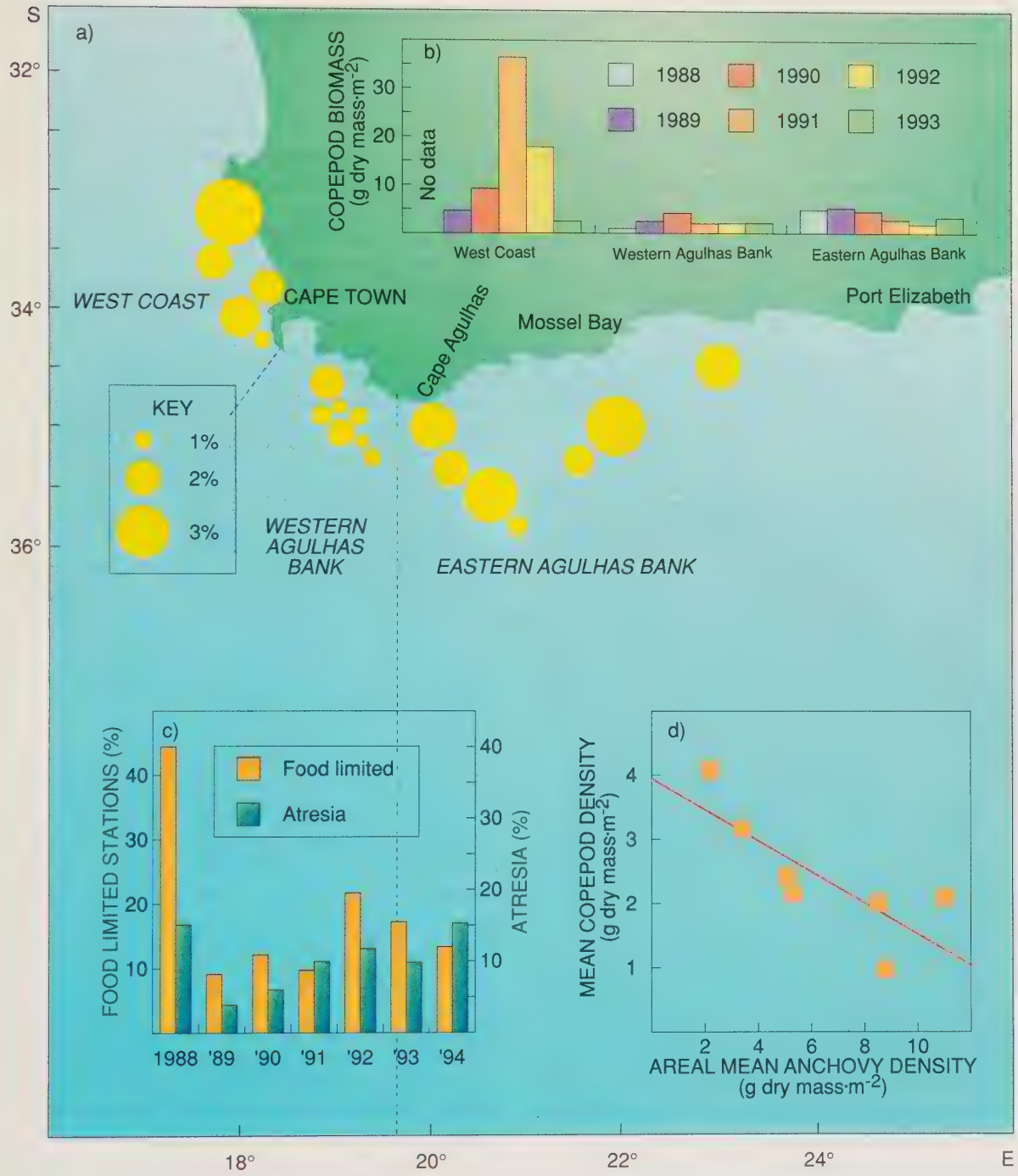


Fig. 20: (a) Spatial distribution of anchovy condition during November 1994; (b) the copepod density measured during November of the years 1988 – 1993 on the West Coast and Agulhas Bank; (c) time-series of starvation index and percentage of female anchovy sampled with oocyte atresia; (d) linear regression of mean copepod density against mean anchovy density on the western Agulhas Bank

from fat reserves in the body and planktonic food from the shelf region.

Since 1988, hydroacoustic surveys conducted each November, midway through the extended spawning season, have included measurements of phytoplankton and copepod abundance, as well as of gonad atresia of female anchovy. These surveys have revealed that anchovy on the western Bank are in a much poorer condition, with lower fat reserves, than those on the eastern Bank or on the West Coast (Fig. 20a). A similar trend is apparent with regard to the abundance of copepods, the preferred prey of spawning anchovy, which is usually at a minimum on the western Bank (Fig. 20b).

A starvation index has been calculated as the proportion of area on the western Bank where anchovy cannot acquire a minimum daily maintenance ration. A time-series of these indices clearly shows that almost half the fish on the western Bank in 1988 were starved, which led to a recruitment failure the following year, whereas in subsequent years the incidence of starvation was much lower (9 – 22%) (Fig. 20c). The same trend is reflected in a time-series of the proportion of fish in a state of gonad atresia (Fig. 20c). The exception to this trend, in November 1994, coincided with an invasion of warm water onto the whole shelf during a period of unusually strong westerly winds, which may have contributed to the unexpectedly high levels of atresia. Copepod abundance on the western Bank appears to be independent of food and temperature, but it is inversely correlated with fish density (Fig. 20d), suggesting a predator-prey relationship. At high densities of fish, there is insufficient copepod food to sustain spawning and so gonad atresia increases, resulting in a shortened spawning season and perhaps poorer recruitment.

Anchovy eggs are transported northwards from the western Agulhas Bank in a strong jet current, allowing the larvae to develop in the productive nursery grounds of the West Coast. Adult fish seem therefore to select an area which favours survival of the young stages, rather than providing a good feeding area for themselves. This contradicts the member-vagrant hypothesis for herring, which have fixed benthic eggs and adults that select a good feeding area for spawning.

It is thought that anchovy remain on the western Bank to spawn, rather than move to a better feeding area, because although suitable temperatures for spawning (16 – 19°C) are found offshore on the West Coast, the eggs may be swept too far from the coast to remain in a food-rich environment for larval development. Alternatively, on the eastern Bank, eggs may be lost in the Agulhas Current, or larval predation by pelagic fish may be unreasonably high. This leaves a rather restricted, suboptimal area available for anchovy spawning, which may limit the population size the area can sustain, despite the high primary productivity of the Benguela upwelling system.

Predicting pelagic fish distribution using satellite imagery

Research has been carried out to investigate whether there is a relationship between sea surface temperature (SST) and the distribution of three pelagic fish species (anchovy, pilchard and round herring *Etrumeus whiteheadi*). The hope is to use satellite thermal imagery to identify where the highest concentrations of fish are likely to be on the fishing grounds. Declouded SST images representing the first 12 weeks of the 1992 pelagic season were examined in conjunction with West Coast commercial catch statistics. Catch distributions were then related to three parameters, absolute SST, the spatial variability of SST (thermal fronts), and the temporal variability of SST (warming and cooling events).

The best results were obtained when catch distributions were compared with absolute SST and SST spatial variability (Fig. 21). These relationships were combined in a two-dimensional

classification procedure which may be applied to any thermal image to predict the relative concentrations of each species on the West Coast fishing grounds. The procedure was tested on three thermal images and the results compared with actual catches. For anchovy the procedure was judged to have been successful in all three tests, for pilchard two of the three tests were successful, but for round herring, for which a scarcity of catches restricted the test to two data sets, marginal success was achieved with one set only. Future work will involve extending the analysis to the entire fishing season, while also striving to improve the relationship for round herring.

Hake-directed longline experiment

Since the closure of the experimental longline fishery for kingklip *Genypterus capensis* in 1990, considerable pressure has been applied to introduce hake-directed longlining. Longlining is seen by some as a viable and less capital-

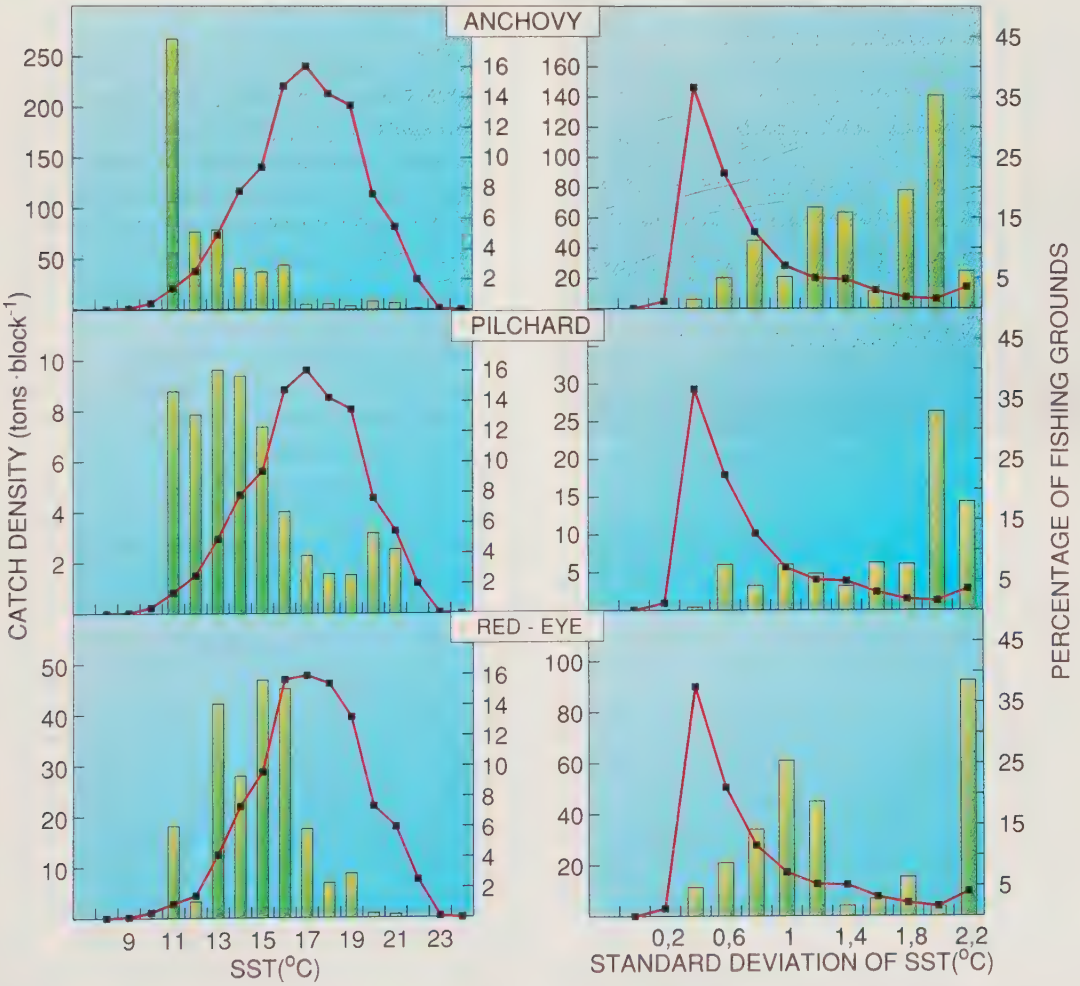


Fig. 21: Catch density as a function of sea surface temperature (SST) and as a function of spatial variability of SST (standard deviation of SST) for three species of pelagic fish. Catch densities are shown as bar graphs and the distributions of SST and SST standard deviation as superimposed line graphs

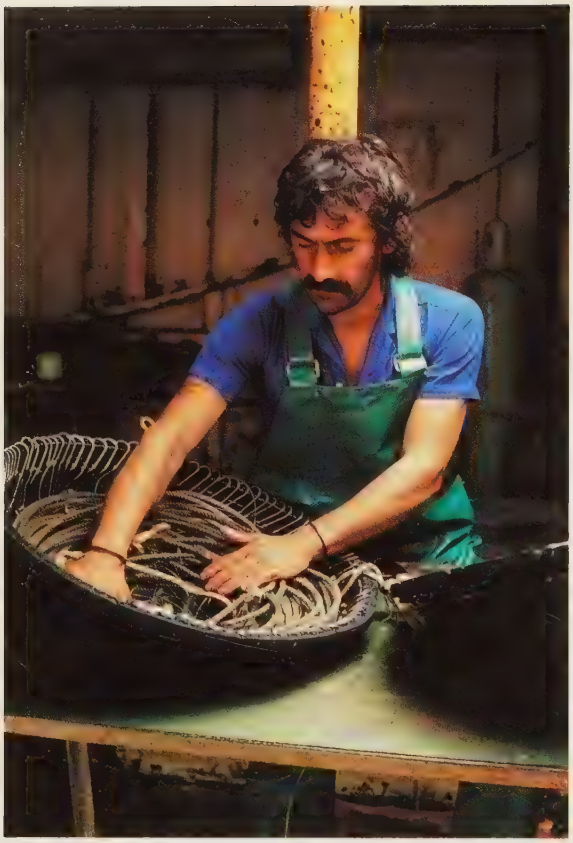


Fig. 22: A longline fisherman preparing a longline basket for shooting a line

intensive method of catching hake, and also a means by which access to the hake resource can be obtained. The issue became a priority when an illegal longline fishery developed in 1991 and 1992. As a result, an advisory subcommittee was formed to investigate the longline issue and to make recommendations to the Minister. The final report of this subcommittee recommended that 3 000 tons of the hake *TAC* be set aside for a scientific and socio-economic experiment to test the viability of hake-directed longlining.

A longline workshop allowing open debate of the major issues by the different interest groups was then convened by neutral facilitators, and central to the workshop was a proposal drawn up by the Institute and independent scientists outlining the experimental strategy. Agreement was reached on the methodology, participation and duration of the proposed experiment, as well as on the allocation of the available quota among the different interest groups.

The experiment was split into two major components. The first investigated the impact longlining was likely to have on hake stocks that were already exploited by a substantial trawling fleet. The second assessed the economic productivity, costs and benefits, and the social implications of longlining as a method of catching hake compared to trawling.

The first phase of the experiment began in May 1994 and ended a year later. Three groups of vessels were identified and each was required to fish in pre-selected areas around the South African coast at specific times of the year. In total, 40 "tuna" vessels (five fishing per month), five "deep-sea" vessels (fishing throughout) and nine "inshore" vessels participated in the first phase (Fig. 22). The "inshore" vessels were required to fish in restricted areas on the South Coast, where the intention was to assess the potential for fishing communities to derive benefit from longlining.

The experimental design in the first year aimed at obtaining information that could be used to assess the effect of longlining and trawling on the short- and long-term productivity of the hake stocks. Direct estimates of selectivity were therefore required for the different gears (longline and trawl), and an intensive sampling programme was designed to obtain length frequency distributions of the hake catches of the different types of longline vessels. Data were also collected in three designated areas (West Coast, South Coast and an area between the two coasts designated "Intermediate") in different months of the year. The information collected was intended specifically to determine the selectivity of trawls and longline gear on both species of hake as well as on the male and female components of the stock. Part of the experimental design provided for direct simultaneous comparative sampling experiments on research,

longline and commercial trawl vessels. Satellite-tracking as a means of monitoring and policing vessels was also investigated.

A three-month moratorium after completion of the first phase was agreed to by participants at the longline workshop to allow time for processing and analysis of the data and for decision-making. The results of the first phase, in conjunction with the socio-economic study, will determine if the second stage of the experiment will be implemented.

Vertical migration of horse mackerel

Important information in any stock assessment includes accurate knowledge of the geographic boundaries of the stock and the effectiveness of the sampling gear being used to census it. In this regard, a demersal survey of the Agulhas Bank during October 1994 demonstrated that the population size of horse mackerel *Trachurus trachurus capensis* there cannot be assessed adequately by means of bottom trawls. This is because a substantial portion of the population on the eastern Bank extends over and beyond the shelf-break, over grounds unsuitable for bottom trawling. A different situation holds for horse-mackerel surveys on the central and western Agulhas Bank, where the fish are not readily detected acoustically in midwater at night. These conditions limit the performance of an acoustic survey, while favouring a bottom trawl survey.

Results from a survey during May 1995 have revoked the previously held belief that horse mackerel on the western and central Bank cannot be observed acoustically in midwater at night because of their limited vertical migration. Horse mackerel migrate extensively into midwater at night on the central Bank, but they are not as readily detected acoustically there as on the eastern Bank. If horse mackerel are to be extensively surveyed acoustically across the whole Aguhas Bank, particular emphasis must be placed on improving the identification and description of night-time echoes of shoals to increase understanding of the dynamics of their vertical migratory behaviour.

Studies of squid concentrations using acoustic tagging

Researching the behaviour and dynamics of squid in large concentrations has always been an important objective in large-scale, fisheries-

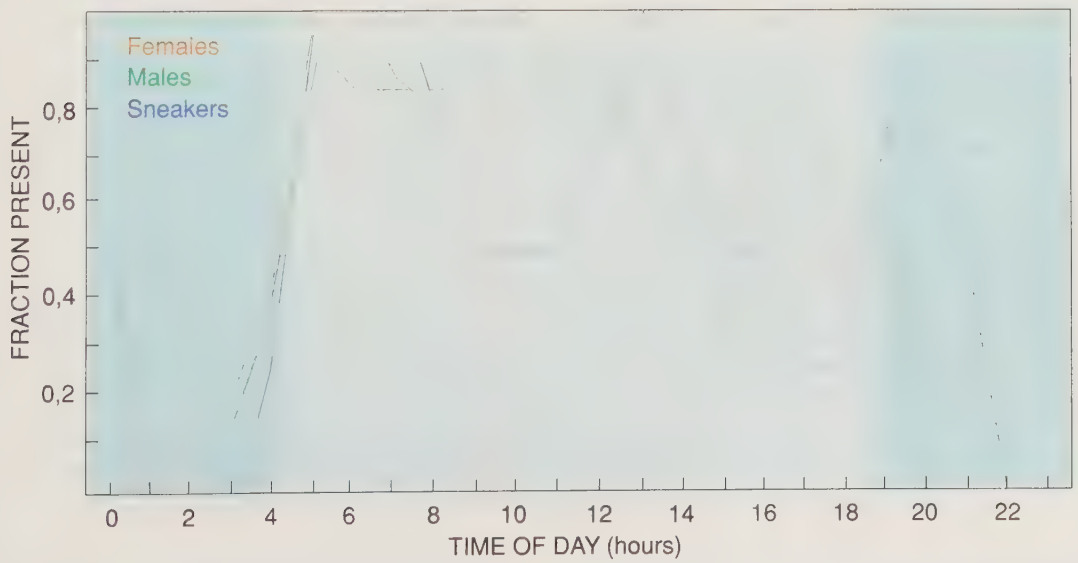


Fig. 23: The presence of three groups of chokka squid on the egg bed over a 24-hour period

oriented programmes. Unfortunately, a lack of suitable techniques has prevented the identification of any patterns in the apparently chaotic "last dance" of spawning squid. However, in a first application of three-dimensional, radio-linked acoustic positioning, details have emerged of individual interactions in large-scale group dynamics of chokka squid. Earlier SCUBA diving studies had shown that concentrations consist of females, large males which pair with females, and small "sneaker" males which try, with frequent success, to copulate with females that are usually already paired. Further information was needed on the residence time of squid groups in these concentrations, which affects catch and spawning rates. Other important aspects are the structure and dynamics of the concentration and the catch. It is now known that proportionally far fewer females are caught on jigs than are present in the concentration, which means that their chances of laying more eggs before they die are improved, but it is uncertain whether this is also the case at night.

A Canadian research team assisted Institute researchers in an experiment to investigate these problems. Squid from all three groups (females, males and male sneakers) were caught, and small acoustic tags inserted into their mantles before they were released. Four moored hydrophones registered their movements for up to seven days, relaying information on position, temperature and jet pressure to a computer system displaying instant graphics, 2,5 km away (Fig. 23). It is apparent that females remain on and above the egg bed longer and more consistently than large males or sneakers, especially at night. It is therefore likely that more females are caught at night, which means that any introduction of effort limitation to protect the resource, should it become necessary, would be most beneficial at night.

Trends in penguin and pelican populations

The African (or jackass) penguin *Spheniscus demersus* is endemic to southern Africa, where it now breeds at 27 localities between Hollams Bird Island off central Namibia and Algoa Bay near Port Elizabeth. Recent surveys conducted by the Institute, in association with Namibian authorities and South African conservation agencies, have shown that it no longer nests at 10 localities where breeding was formerly recorded or suspected. Furthermore, the total population is continuing to decrease.

Census methods that have been applied through the 20th century are not strictly comparable, but

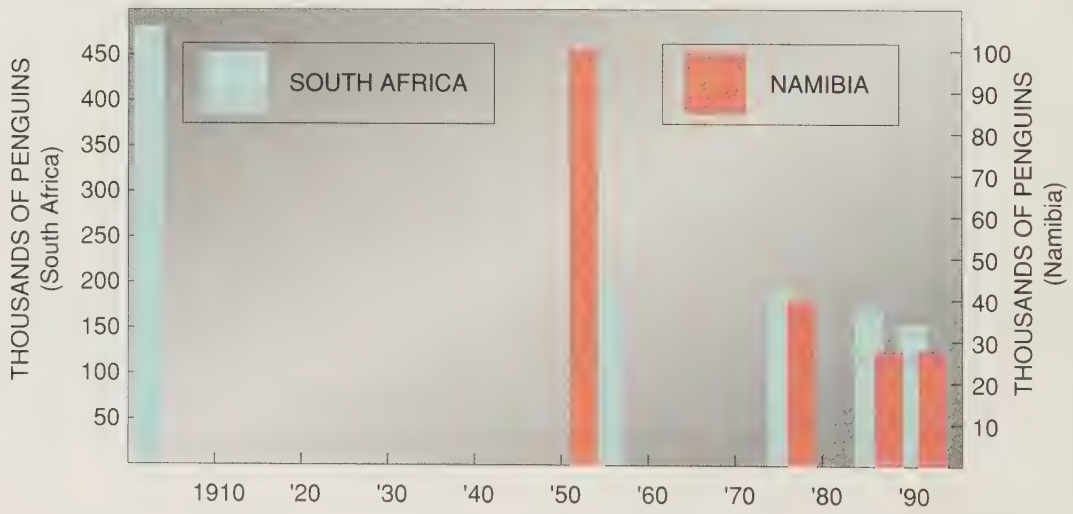


Fig. 24: Population trends of penguins off Namibia and South Africa during the 20th century

it is estimated from records of egg harvests that there were at least 575 000 adult African penguins at the start of this century. By the 1950s, aerial photographs showed that numbers had halved to about 296 000 adults. The declining trend continued, so that by the 1990s counts of breeding and moulting birds indicated that the adult population stood at only 180 000. This means that, in the 20th century, the adult population has been reduced by 70%, with a mean rate of decrease of about 1,3% per annum. At present, the Namibian population numbers fewer than 30 000 adults and the South African population about 150 000 (Fig. 24).

At the start of the 20th century, the main threats to African penguins were at its breeding colonies, especially because of egg harvests, but also through disturbance caused by guano collecting. As the century draws to its close, the main threats are oil spills and competition with seals and the fishing industry for food.

The potential of oil spills to devastate penguin colonies was emphasized in June 1994, when the *Apollo Sea* sank between Dassen and Robben islands. Oil reached the beaches of the two islands and fouled about 10 000 penguins. Approximately half were successfully rehabilitated and returned to the wild, but the rest died. The spill occurred during the main breeding season and, despite more than 1 000 chicks being hand-reared, it is likely that many died when their parents succumbed as a result of oil-fouling or were held in captivity for rehabilitation (Fig. 25).

Censuses in early 1995 indicated a slight reduction in the number of breeding penguins at Robben Island, but an unexpected increase in numbers at Dassen Island. As food appears to be more readily available than in 1994, this probably results from good recruitment to the breeding population and a higher proportion of breeding birds.

Historical surveys of the Western Cape population of great white pelicans *Pelecanus onocrotalus*

Fig. 25: Institute staff helped clean penguins oil-fouled during the Apollo Sea *disaster*

collated during the past year have been more encouraging. This population is isolated from South Africa's other breeding population at Lake St Lucia, as well as from the breeding colonies at Hardap Dam and Bird Rock Platform in Namibia, although the possibility of interchange between the populations requires further study. The Western Cape population probably bred at Robben Island in the early 1600s. From 1869 to 1919 breeding was recorded at Dyer Island, and from 1894 to 1902 at Quoin Rock. From 1930 to 1955, great white pelicans bred at Seal Island in False Bay. In 1956, they moved to Dassen Island, where they have bred ever since.

The pelicans were probably displaced from each of their former breeding localities by disturbance

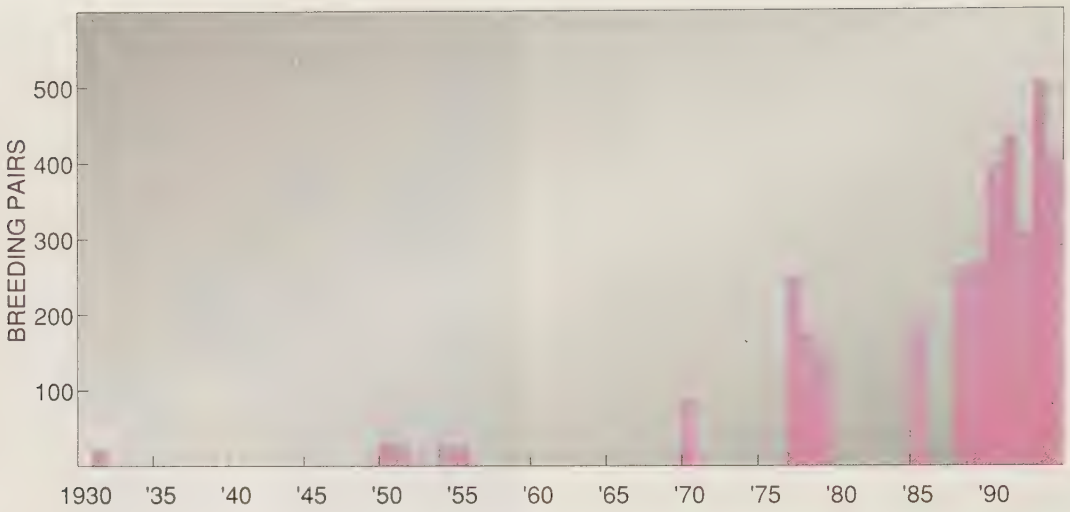


Fig. 26: Population trends of pelicans in the Western Cape during the 20th century

from man or seals *Arctocephalus pusillus pusillus*. In the early part of the 20th century they were persecuted at Dyer Island because they preyed on guano-producing birds, such as the Cape cormorant *Phalacrocorax capensis*. At Quoin Rock and Seal Island they were ousted by expanding seal herds, so that by 1955 their nests at Seal Island were restricted to the roofs of huts. At that stage the population numbered about 25 breeding pairs. After the birds moved to Dassen Island their numbers recovered from about 90 pairs in 1970 to perhaps 250 pairs in 1980. The colony then remained stable until 1985, after which there was a rapid increase (Fig. 26), and by 1993 the population stood at 504 breeding pairs.

Various factors may have influenced this favourable trend. The most important has probably been the move to Dassen Island, where the birds have been undisturbed and have had plenty of space to breed. An increased number of water bodies in the Western Cape, some stocked with introduced fish, and availability of agricultural and fishing offal are likely to have increased the food base.

West Coast seal mortality

During June 1994 the first reports were received that many of the year's crop of seal pups, born in the last two months of 1993, were emaciated and starving at colonies in the Lüderitz area, north of the Orange River. Subsequent reports were of heavy mortality to seal pups at the Cape Cross colony, followed by news of thousands of aborted foetuses and dead adults being found along the shore. It soon became clear that this was a natural disaster on a grand scale.

Namibian fisheries vessels which sailed from Walvis Bay to survey the marine environment found that all fish stocks, including the non-commercial pelagic goby *Sufflogobius bibarbatus*, appeared to be severely depleted or undetectable. The pelagic goby is an important forage fish for seals in Namibian waters. This did not appear to be a result of overfishing, but rather that fish had moved out of the area, possibly northwards into Angolan waters because of unfavourable environmental conditions.

Although there were suggestions that the seal mortality might be due to a virus or some other disease organism, no evidence for such a cause could be found. The emaciated condition of the seals and the evidence of fish scarcity made it clear that the mortality could be attributed to starvation. By the end of 1994, almost all the pups belonging to the 1994 year-class from the colonies north of Lüderitz had died, as well as

thousands of adults, and many times this number of aborted foetuses, which in turn will result in a depleted 1995 year-class. The true scale of this natural disaster for seals, the worst along the Namibian coast in living memory, will only be known once the aerial photographs taken in December 1994 and again in December 1995 have been analysed.

As the South African and Namibian seal population is continuous along the West Coast, it was considered possible that the unfavourable environmental conditions might spread south and lead to a mass mortality in the South African segment of the population. However, measurement of the average weaning mass of pups at Kleinsee, South Africa's largest colony, revealed that their mass in August and October 1994 was normal for that season. There was also no visible evidence of unusual mortality at the colony among either pups or adults. Furthermore, a photographic aerial census of Kleinsee conducted in December 1994 showed that the number of new-born black pups counted, although some 17% lower than in 1992, was within the normal bounds of variability. It did not, therefore, appear that unusual environmental conditions were affecting seals south of the Orange River during 1994, but monitoring continues during 1995.

Antarctic krill research

The Institute undertakes research on Antarctic krill *Euphausia superba* to assess the species' resource potential, as part of South Africa's commitment to the 23-nation Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). A highlight in 1994/95 was the hosting of four international meetings sponsored by CCAMLR in Cape Town to address various problems associated with managing the Antarctic krill fishery. Important scientific contributions to these meetings were made by Institute scientists in respect of developing "decision rules" to obtain scientifically based standards for such management.

Significant scientific advances have also been made on a range of topics pertinent to managing the krill fishery. Various statistical models applicable to the development of *cpue* indices have been developed from the Institute's acoustic database on krill aggregations, collected during seven cruises to the major krill fishing grounds. These models have also been applied to address problems associated with the design of surveys to estimate krill biomass and availability. Similar models are likely to have application in improving descriptions of local resources such as anchovy and pilchard.

Other developments have aimed at improving present estimates of krill acoustic target strength. In addition, a model describing functional relationships between krill and its major predators has been developed. It has indicated that, in years of low production and abundance, fishing may exert a profound influence on the dynamics of predators utilizing krill as their primary source of food.

TECHNOLOGICAL ADVANCES

Research and development

The past year has seen the fruits of vigorous research and development in several areas of instrumentation within the electronics and mechanical workshops. The "U^3" (Universal Underwater Unit) has operated very successfully in trawling operations since it was developed several years ago. It measures temperature, depth and flow rate. The year saw the development of a prototype U^4 unit, a unit with greater depth rating, more versatility in attaching components such as fluorometers and turbidity meters, and the possibility of merging with a CTD on the same communications line. Modem communications replace frequency-shift keying to provide the necessary speed, an in-house researched application. In line with the trend towards microprocessor applications, the U^4 has made significant shifts away from analogue circuitry.

The prototype Weller rotor current meter has now been completed and tested 1 m below an Aanderaa RCM4 unit in 96 m of water west of Cape Columbine. The mean-flow results were in good agreement at this depth, where swell rectification by the RCM4 is not severe. As anticipated, the spectra differed, the in-house unit showing a better response to mooring motion. Some problems remain with the rotor bearings and two variations are under test. A total of 40 units will now be built at a cost roughly 10% of that of imported equivalents.

Fig. 27: The microlayer sampler built by the Institute collects contaminants that accumulate in the 40-µm-thick surface layer of the sea

Further, the local unit is more advanced in its low-current design. Maintenance and data retrieval are simple, effecting a great saving in manpower and computation.

To monitor near-surface temperature, recording sensors are maintained at 11 sites along the South and West coasts, typically 10 m deep. Commercial instruments were used initially, but these will be phased out by devices developed in-house. They are a fraction of the cost of the imported units and are constructed as twin systems in a common housing, giving greater reliability in maintaining continuous time-series.

Pollution control

A remotely controlled microlayer sampler has been built according to local needs (Fig. 27). The instrument has seen service at various sites, notably near the Green Point sewage outfall. The device collects a slice 40 µm thick at the sea surface, where contaminants aggregate and impact planktonic eggs and larvae. It can be launched from a small boat or from the shore and can operate in 2-m swells and winds of up to 15 knots. There are controls for vehicle speed and direction and drum speed.

Acoustic technology

A knowledge of fish reflectivity (i.e. target strength) is essential for making estimates of fish density and abundance from echo-integrator surveys. Target strength is best estimated by isolating and measuring echoes from individual fish *in situ* by means of a split-beam echo-sounder. The chief difficulty in applying this technique to pelagic fish is that, even at night, densities are often too great for reliable isolation of echoes from single fish using current methods of single-target recognition. The result is that the target strength for such species is usually overestimated. Ways have therefore been sought to improve the methods of discriminating between echoes from single and multiple targets, and of removing the effect of multiple echoes by judicious post-processing of target-strength distributions.

A new discriminator, which relies on differences in the interference patterns produced by single and multiple targets in the elements of the split-beam transducer, has been tested by computer simulation and found to be both more effective and less biased than conventional phase-based discriminators. A discriminator employing this method is to be constructed and tested before the end of 1995. The post-processing techniques developed have enabled convincing regressions of target strength against length to be obtained for anchovy,

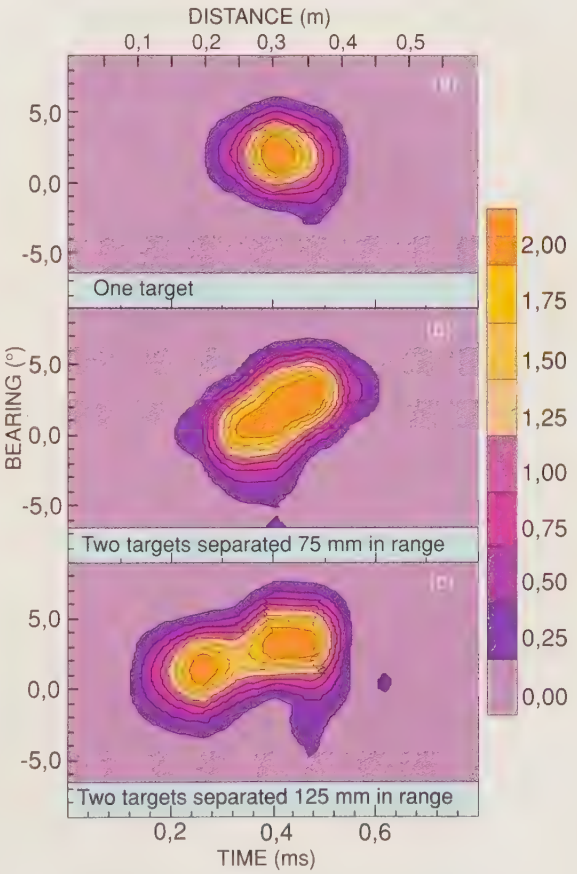
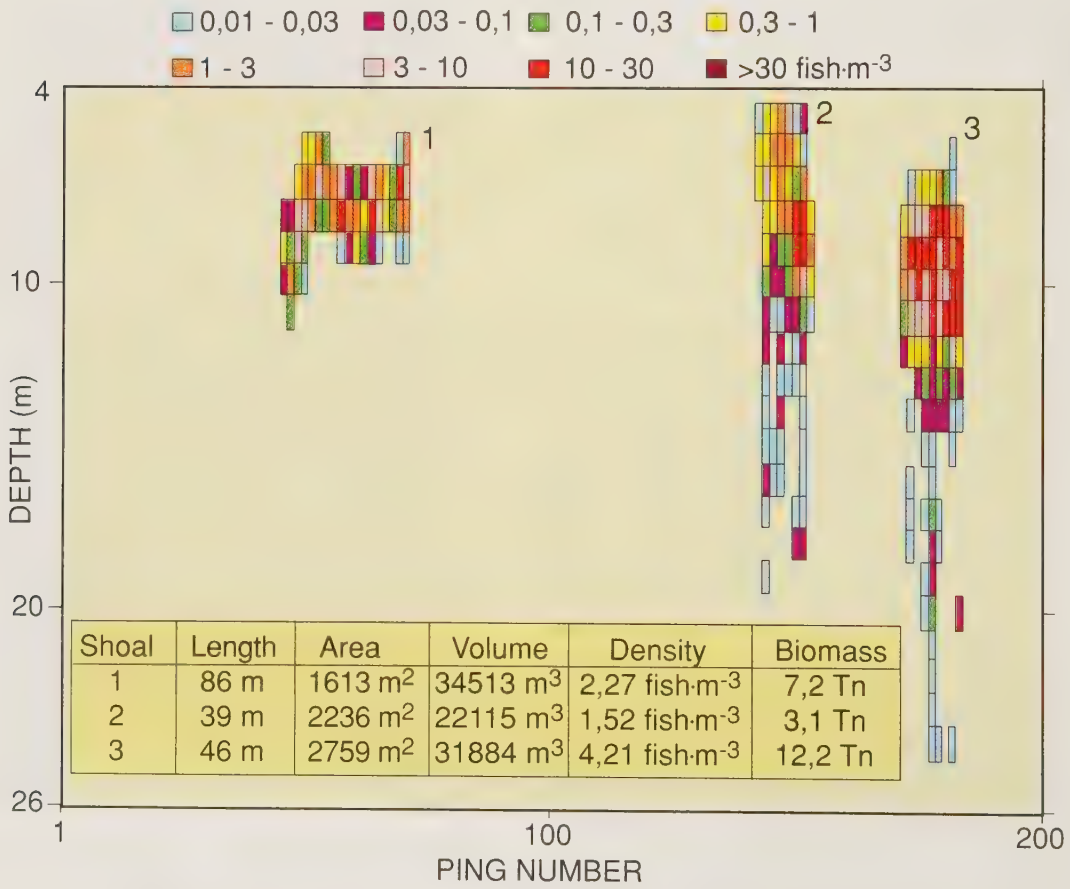


Fig. 28: Signals produced by the prototype ABACUS echo-sounder from acoustic sources in a test tank

pilchard and horse mackerel. The anchovy relationship, for example, yields an average estimate of spawning biomass for the period 1984 – 1994 which agrees to within 10% with estimates obtained by the egg production method.

ABACUS (Advanced Beam-former for Acoustic Counting of Underwater Scatterers) is a multi-beam, high-resolution echo-sounder for counting fish at densities too high for resolution by conventional systems. The primary aim is to count individual fish at densities well beyond the limit for *in situ* target-strength determination, and so to estimate density in situations where the target strength cannot be estimated directly, even with the new methods outlined above. An eight-beam prototype has been constructed and tested successfully on closely spaced acoustic sources in a test tank. Figure 28 shows the signal from a single target, two targets 2,0° apart and separated by 75 mm, and two targets 2,0° apart and separated by 125 mm. A full 16-beam system is now under construction and scheduled for sea trials before the end of 1995.

Geostatistics is a discipline that aims at detecting, describing and making use of the spatial structure inherent to natural phenomena. In the past year, some of these techniques have been used to describe the structure of co-existent pilchard and anchovy populations, as detected during acoustic surveys of spawner biomass. The objective was to ascertain if differences in patterns of spatial dispersion of the two species would require modifications to future acoustic survey design. This exercise was considered of



Shoal	Length	Area	Volume	Density	Biomass
1	86 m	1613 m^2	34513 m^3	2,27 fish·m^{-3}	7,2 Tn
2	39 m	2236 m^2	22115 m^3	1,52 fish·m^{-3}	3,1 Tn
3	46 m	2759 m^2	31884 m^3	4,21 fish·m^{-3}	12,2 Tn

Fig. 29: Identification and characterization of three shoals of pilchard by means of SHAPES

importance because present surveys are adapted to the life history strategies of anchovy, rather than pilchard. As the pilchard resource continues to recover and the anchovy biomass declines, albeit temporarily, future surveys would need to be adapted to the particular spatial structure of pilchard. Preliminary results indicate that pilchard occupy space in a less structured and more patchy manner than anchovy. This can be explained partly by the more complex age structure of pilchard populations during the time of sampling. Clearly, if future surveys are to be targeted on pilchard, the transects should be closer together and the survey coverage fairly uniform over the entire survey area. These ideas will be put into practice this year.

SHAPES, or Shoal Analysis and Patch Estimation System, is a computer program developed to identify fish schools and plankton patches from echo-charts. Once adequate data bases have been compiled, the system can be used to develop objective criteria to identify the species of fish in any particular shoal from the characteristics of its echo. The system would also allow scientists to compare the aggregative properties of different fish species, such as packing densities and empirical limits to school sizes, as well as to quantify zooplankton patchiness on the spawning and recruitment grounds. In all, 16 parameters are calculated for each school, including morphological (size, shape, internal characteristics) and relational (nearest neighbour distances) variables. Each school is also geographically positioned, and some basic environmental information is attached to it. An example of SHAPES' performance is shown in Figure 29.

PUBLICATIONS

In the 29 years since 1966, the year marking the revival of the *Fisheries Bulletin*, this Institute and its predecessors have been associated with some 2 337 published works, at a mean of 81 per year. The number of publications has more than doubled each decade, 11% being produced in the first, 27% in the second and 62% in the nine completed years of the third decade. In each publication category, namely in-house, other local and overseas, the increases have been consistent. However, the mix of publication categories has changed, from 48% in-house, 30% in other local media and 22% in other countries in the first decade to greater publication outside (35% each in other local media and overseas) in the second decade. In the past incomplete decade even more were channelled to other local media (43%) and there was a partial restoration of in-house publication (34%), both at the expense of publication abroad (23%).

In 1994, Sea Fisheries was involved in 131 publications. This is 54 less than last year and is entirely due to fewer publications in other local media, because in-house and overseas publications increased slightly (41 and 47 respectively). Whereas the advance abstracts of the eighth South African National Oceanographic Symposium were listed in 1993, the only proceedings of a South African meeting listed this year are from a workshop held in October 1992 to synthesize knowledge on the physical, chemical and biological characteristics of the Agulhas Bank. The proceedings were published in *South African Journal of Science* and contained 10 contributions with staff involvement.

In-house publications this year amounted to 30 papers in *South African Journal of marine Science* **14** (19 with staff participation), *Investigational Report* **134** on seal pup numbers, and eight contributions by staff to the booklet on the deep-sea environment published with the sponsorship of a fishing company for National Marine Day.

Of the 131 works listed, 59% were written by staff, 33% were done in cooperation with non-staff (mostly local) and the remainder were contributed to the Journal by other local (5 papers) and overseas (4 papers) scientists, two papers being cooperative efforts between these two author categories.

The contributions listed hereafter were the work of 137 different authors (74 staff, 47 other local and 16 overseas). The composition of the 172 authors in 1993 did not differ markedly from this. If the identity of authors is disregarded, the total authorship of the 131 papers in 1994 amounted to 278 (193 staff, 64 other local and 21 overseas), compared to an authorship of 381 last year with a similar composition. As in the past, most authors were involved in a single paper in 1994 and this ranged from 38% for staff to more than 70% for non-staff contributors. Staff involvement decreased gradually to two authors who participated in eight papers. Other local and overseas participation was confined to three papers, except for one local author who had a hand in five. Similarly, most (40%) of the papers had a single author, multiple authorship decreasing steadily to one paper with seven authors. Last year multiple authorship practically ceased at five papers each with six authors, although there was one with nine authors and another with 13 authors.

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